A STUDY OF STARCH

A Thesis

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Preface.

Due to the lack of scientific data, choice of a particular type of starch for a particular number of yarn, or a certain texture of fabric, or a certain preparation of printing paste has, in the past, been governed almost entirely by the experience of the user. It was thought that a study of the viscosities of the different starches would be helpful in this connection. In this paper the more important types of starch and starch derivatives used in the textile industry are studied. First, a study of the literature covering the history, methods of manufacture, chemical structure, methods of identification, uses, etc., was made, so that a comprehensive understanding of the field might be had. In a synopsis such as this, it is more convenient to interpret rather than quote all the quantitative evidence that has been published, but it is believed that numerical justification for every statement that is made can be found in the papers referred to in the references.

The second or experimental part of this paper embraces the behavior of starch solutions under varying conditions of temperature, time, acidity and alkalinity and the results plotted, so as to show the corresponding variations in viscosity. It is hoped that this data will throw some light upon the physical properties of the different starch solutions.

The photo-micographs were taken by the writer, using reflected light. Had transmitted light been used, the markings on the starch granules would have been stronger, but it was impossible to use this type of light with the apparatus on hand.

CONTENTS.

The History and Early Development of Starch Chemistry and Manufacture.

The use of starch in paper manufacture dates back to the early ages. One of the first uses for starch was in the production of papyrus. In this method, layers of papyrus were cemented together by starch and the surface sized in order to prevent absorption of the ink. The permanence of these sizing materials is demonstrated by the fact that to-day many of these specimens are preserved in museums, and show satisfactory resistance to printing and writing inks. It seems reasonable that starch would be one of the first natural products to be used by man, since it is found so abundantly in many plants, roots and cereals, and the first accounts of technology contain treatments of its preparation and utilization.

Strips of Egyptian papyrus, pasted together with starchy materials, have been found in tombs thought to have been buried as far back as 3500 B.C. Pliny (1), about 70 A.D., describes the method of pasting or sizing papyrus in order to obtain a smooth surface that will not absorb ink. By this method, fine wheat flour is boiled with a weak solution of vinegar, and the resulting paste applied over the surface of the paper. After pressing the papyrus and beating it down with a mallet, a second layer of paste is applied and the process repeated. Pliny mentions sheets prepared in this way, then two hundred years old and still in a good state of preservation.

Some of the earliest specimens of paper were sized and weighted with crudely purified starch. (The difference be-

tween paper and papyrus is in the fact that paper is made by pulping or felting a fibrous material and then depositing this upon a plane surface, whereas papyrus is made by joining strips of the plant together in such a way that the original fibrous structure is preserved.) Wiesner (2) reports a Chinese document clearly dated 312 A.D., which unmistakably contains starch sizing. Wiesner also has examined more than five hundred oriental papers, dating from the fourth century to modern times, and finds that most papers manufactured between 700 A.D. and 1300 A.D. contain more or less starch size.

It seems that the procedure was to add first a more or less modified starch to render the paper ink resistant, and then give it a heavy coating of unmodified starch to add weight and thickness. Granules of rice, wheat and barley starch have been identified on these old papers. The technique of paper making and sizing was apparently incorporated from the Chinese by the Turks, Arabians and Persians.

This practice of starching papers seems to have been abandoned toward the end of the fourteenth century, and was not readopted until comparatively recent times.

Starch was early recognized as an important dietary component, and Hyppocrates (3), about 380 B.C., states that starch has a certain medical value. Abu Mansus (4), an Arabian teacher and pharmacologist, about 975 A.D. was well acquainted with various uses of starch, and even describes its conversion by saliva into a material which was called "artificial honey" and used for treating wounds. This is probably one of the first references to the enzymic hydrolysis of starch to

dextrins and maltose.

Very little is known concerning the early use of starch on textiles. Pliny makes passing mention of its use for whitening cloth and, at the same time, he mentions its use for powdering the hair.

The first description of the preparation of starch is given by Cato (5) about 170 B.C. in his treatise on Roman agriculture. A translation of the method is as follows:

"Carefully clean the cereal, place in a shallow vessel and add water twice a day. On tenth day drain off water, press out thoroughly, stir with water in a clean vessel and allow to stand until material is deposited. Wrap the deposit in a clean linen cloth, press out the creamy liquid into a clean vessel or into a mortar, and after this levigate once more. Place the vessel in the sun, allow to dry, and when dry place the starch in a fresh vessel.

Pliny (1) describes its preparation also, and says that the highest grade of starch is made at the island of Chios, the products from Crete and Egypt being next in order of quality.

During the next two thousand years the manufacture and use of starch were only gradually developed, and the manufacture only became of industrial importance about the middle of the nineteenth century.

Starch seems to have been introduced into England during the reign of Elizabeth, who is said to have appointed a special court official for laundry starching.

In 1564 Mlle. van der Plane, a Flemish woman, establish-

ed a training school in London for the purpose of teaching the art of starching. The women could come there, pay so much per lesson for the training. It seems that, at this time, the preparation and use of starch were considered household accomplishments.

It was the fashion in those days to wear many ruffles and frills, and it was necessary for these to be starched before they would stand up in proper position. It was customary to color the starches and then when they were applied, the fabric was both dyed and starched in the same operation. It seems that yellow was used on clothing for men of fashion, green for Cavaliers, and blue by Roundheads.

In 1638 a charter was granted by Charles I "for the remedying of many great abuses and inconveniences then complained of by the excessive and disorderly making of white starch in many places within the Realm by the converting and consuming of great quantities of wheat and other grain fit for man's food, into starch."

In 1661 a new charter was granted by Charles II "Sundry meet persons of the said trade of starch making with Power and Privilidges to meet them and to their successors to make or cause to be made, in one joint stock and not otherwise, in such convenient place or places as shall be appointed by us--- and all manner of whate Starch with Bran and Pollard only, or with wheat corn or Grain imported from beyond the seas, or with musty, defective and unwholesome corn, unfit for the food of man, and not of any wholesome corn or grain of the growth of the Realm."

In the eighteenth century, cheaper sources of starch than wheat were sought for, and in 1732 the Sieur de Guife recommended to the French Government that potatoes should be used for the manufacture of starch and, in Germany, the potato starch industry, sponsored by Frederick the Great, dates from 1765.

Duhamel du Monceau (6), in 1772, observed that when cereals were scarce, other sources of starch, such as potatoes, arrowroot, etc., could be used for this purpose. He describes the methods of manufacture at that time, and mentions that starch was used in making cosmetic powders by dyers in color printing, by confectioners, and by soap manufacturers as an ingredient in certain classes of soap.

"The Universal Lexikon" (7), in 1744, briefly describes the function of starch in textile sizing, and states that warp glazing is entirely necessary, as otherwise, the threads cannot withstand the strain to which they are subjected.

The Montyon Prize of 1780 was awarded to Roux by the Academie des Sciences for introducing starch for dusting foundry moulds.

Pomet (8), in 1725, states that starch made in Paris is superior to all others, and that products dried by artificial heat are not as good as those dried in open air, due to a grayish color developed during baking.

Fourcroy (9), in 1792, says that starch on dry distillation, pyromucic acid, a little oil and a great deal of carbon dioxide is formed, leaving a residue of light voluminous charcoal in the retort. He states also that the starch is dis-

solved by boiling water, and forms a gelatinous glue on cooling; that sulphuric acid carbonizes starch; that nitric acid converts it into carbon dioxide and oxalic acid; that it appears to be a compound of hydrogen, carbon and oxygen, and is, in many respects, like the gums. He states also that, under certain circumstances, it appears to be converted into a gummy material like a saccharine substance.

The nineteenth century witnessed an enormous expansion in the starch industry, due largely to the development in textile and paper industries.

One of the most important periods in the development of the starch industry was the discovery of starch sugar by Kirchhoff in 1811 (10). His results in the conversion of starch were immediately duplicated by many chemists and, in less than a year following his discovery, the commercial manufacture of starch sugar or glucose had been established.

It is interesting to note that Kirchhoff (11) was also the first to report the conversion of starch into maltose by the enzymic action of the glutinous component of malt. These two discoveries of Kirchhoff marked the beginning of true scientific investigation in this field and, at the same time, contributed to the expansion of the starch manufacturing industry.

From the beginning of the nineteenth century, potatoes have been largely used for starch manufacture (chiefly in Germany), followed by corn, which is the principal raw material in the United States. From about 1850, rice also has been employed in large scale production.

Sources and Manufacture of Starch.

Nearly all plants of the higher orders of vegetable life contain starch as one of their constituents, but this starch is not always in such quantities or form as to be suitable for production on a large scale. This starch occurs in the root-stocks, root-nodules and pith of most plants, and in the seeds of fruit as stored up food for the coming year, for the development of the embryo, and for the continuation of the general growth of the plant.

There are many starches from many different sources on the market, including corn, wheat, potato, tapioca, rice, sago and buckwheat, but it will only be necessary to outline the methods for the production of corn and potato, as the remaining varieties of starch are produced by more or less the same processes.

The Manufacture of Corn Starch.

Indian corn or maize is the principal source of starch in the United States, and was grown by the different tribes of Indians at the time the European discoverers first reached the coast of North America. Columbus reported large fields of it, and even carried some of it back to Europe with him.

The following data by Moffett (15) may be taken as a fair analysis of the corn kernel:

Moisture	11-20% (depending on season)		
Ash	1.2-1.3%;	Pentosans	7.7.5%;
Oil	3-4.5%;	Fiber	1.2-1.5%;
Starch	60-65%;	Proteins	8-10%.

In the preparation of commercial starch, the starch granules have to be separated from the vegetable substances in which they occur, so it is necessary to crush up the grain and break up the cells in which the starch is contained.

According to Moffett (15), one bushel of corn will yield approximately:

32.5 lbs.	starch	6.9 lbs.	gluten meal
20.8 "	feed	5.8 "	corn bran
1.5 "	corn oil	2.0 "	germ oil meal
		5.3 "	steep water

Total 54 lbs.

In the sulphurous acid method for the manufacture of corn starch, we have the following steps or processes:

1. Cleaning.
2. Steeping.
3. Grinding.
4. Sieving.
5. Tabling.
6. Washing.
7. Drying.

1. Cleaning: This first process consists of passing the corn through fanning mills which blow out the chaff and lighter particles, while electro-magnets draw out any metal that may be in the grain, and which might break the machinery later on in the process.

2. Steeping: After being cleaned, the corn is transferred to large steeping vats containing water and sulphur

dioxide, and allowed to remain thirty to forty hours until the grains are softened and ready for grinding. The steep water from this process may contain:

Ash	20%
Protein	38%
Organic Matter	49%
Gravity Degree	Baumé 5 degrees
pH Value	4
SO_2, free	.03%

After being evaporated to about eighteen degrees Baumé, this liquor is used to spray over corn gluten feed during drying.

3. Grinding: The softened corn kernels are next passed through a grinding operation in which the grain is cracked, but leaving germs to pass through uncracked. The germs contain practically all of the oil, and are separated from the rest of the kernel by flotation in water, where the lighter germs may be skimmed off and extracted for edible oil, etc.

4. Sieving: The residue remaining after the removal of the germs contains starch, gluten and fibrous material. This is mixed with water and reground in a Buhr-stone mill, and the semi-liquid mixture passed over shaken, inclined, bolting sieves of about two hundred mesh, mounted on shaking apparatus. The starch, with most of the gluten, is washed through the bolting cloth, while the fibrous material is deposited at the lower end of the sieve.

5. Tabling: The starch and gluten liquor is then agitated in tanks, and its density adjusted to six to seven de-

grees Bé. The suspension is then passed slowly over inclined troughs or tables. Large pipes pass along the head of tables, three to six inches in diameter, and discharge the starch liquor on to the tables. As the liquor flows slowly down the table, the starch granules, which are relatively heavy as compared with the gluten, will be deposited, while the gluten will flow down the table and be run off by troughs, to be used for other purposes.

When starch is eight to ten inches in depth at the head of the table, the flow is stopped, and any gluten remaining on the surface is removed by wooden sweeps. Deposited starch is then washed and partially dried. This wet or "green" starch contains about forty-five per cent water, and may be converted either into glucose,or dried and marketed as starch.

7. Drying: The starch is taken from the settling tables, broken up and placed on carriages, which move slowly through drying tunnels. The drying tunnel is heated by means of a constant stream of dry hot air. This starch, thus dried, may now be converted into any one of several forms, and placed on the market as such. The following forms are the ones most often met with:

1. Pearl Starch - Dried eighteen to twenty hours at one hundred sixty to one hundred eighty degrees F.

2. Crystal Starch - The partly dried starch is placed in kilns in the form of compact cubes, and slowly dried for a number of weeks. After a time, the cube contracts and collapses, forming the distorted crystalline prisms.

3. Powdered Starch - Produced from pearl starch by

grinding and sifting.

4. Lump Starch - Produced by treating powdered starch with steam, and subjecting it to high pressures.

The Manufacture of Potato Starch.

As in the manufacture of corn starch, it is necessary to separate the potato starch granules from the other components of the potato and, in order to do this, several processes are necessary.

Litner gives the following average values for the components of the potato:

Water	76%
Nitrogeneous substances	2.1%
Fat (Ether extract)	0.2%
Starch value (Starch sugar)	18.7%
Other nitrogen-free extract	1.0%
Raw fiber	0.8%
Ash	1.2%

In the separation of the starch granules from the other parts of the potato, the following steps or processes are necessary:

1. Cleaning and Washing Potatoes: As the potatoes come to the starch plant, they contain a large amount of dirt, which is partially removed by unloading them from the wagons to iron gratings, through which most of the dirt is passed before the potatoes enter the plant. From these grating machines, they are usually washed through long concrete troughs into washing machines, where the potatoes are slowly turned beneath a good supply of flowing water.

2. Disintegrating: After washing, the potatoes are transported by means of elevators to the grating or pulping machines, where they are ground into a pulp. This process is usually carried out in two steps, the first grinding producing a coarse pulp; from this mill, the pulp is transferred to another mill, where the pulp is ground still finer. Due to the tendency of the potato pulp to turn red or black, it is necessary to keep a stream of sulphurous acid playing over the grinding blades to keep the liquor reduced.

3. A series of brush cylinder sieves is used in washing out the starch from the disintegrated potato gratings, insuring a thorough separation.

4. Starch Tables: In this process the starch is separated from the highly diluted milk form by passing slowly over long inclined tables containing veins or partitions, which tend to slow up the rate of flow. The starch being relatively heavier than the fibrous materials, settles out and may be removed with scoops, while the lighter materials are carried on down the trough,and caught in a cross-trough or container at the end of the table.

Sometimes these starch tables are replaced by centrifuges, which separate the starch from the diluted potato juices.

5. Washing Equipment: After this separation, further purification is necessary to prepare a dry product, free from all objectionable characteristics. This is accomplished by repeated washing in agitating tanks, or by treatment with running water in clean channels or "tables".

The washing tanks are usually constructed of concrete,

cylindrical in shape, and fitted with revolving stirrers which keep the starch solution in constant motion during the washing process. The starch is then allowed to settle, the liquor drawn off, and the operation repeated until a pure clean starch is obtained.

When the tables are used in place of the tanks, the process is very similar to section four above.

An addition of a small quantity of sulphurous acid may greatly accelerate the settling process and, at the same time, produce a decided bleaching action. Sometimes an addition of potassium permanganate is made before the sulphurous acid, in order to get a better bleaching action, but care must be exercised, or else the adhesive properties of the starch will be affected.

6. Moisture Content: The starch, as it comes from the washing process, contains from fifty to fifty-two per cent water, and is too wet to be dried with heat without danger of partial gelatinization. It is, therefore, necessary to partly dehydrate by means of centrifuges, which brings the moisture content down to thirty-six to thirty-eight per cent. The starch is then pulverized by special powder mills, and forwarded to the drier.

7. Drying Equipment: The starch is next spread in thin layers upon frames and exposed to a gradually increasing temperature up to thirty-five degrees C., or at most thirty-eight degrees C. The machinery consists of a number of endless cloths arranged one over the other, and moving in opposite directions. A temperature of about thirty degrees C. is main-

tained in the upper part of the machine, and is increased to about forty-five degrees C. in the lower part. The starch falls from the top cloth to the one immediately below, where it is picked up and carried to the opposite end of the machine, where it is dropped to the next cloth, etc., until it is finally discharged from the bottom of the machine in the dry state.

8. Sifting and Bolting: In order to prepare the starch for commercial distribution, it must be brought to the required degree of fineness by mechanical means. There are two types of machines generally in use:

(a). The centrifugal sifting machine.

(b). The plane sifter.

A typical type of a centrifugal sifting machine consists of a horizontal cylinder sieve rotating slowly in one direction, and a number of stirring vanes rotating in the opposite direction at a higher speed.

The plane sieve consists of a number of sieves placed one over the other, the top sieve being of coarse mesh and decreasing in size down to the last or bottom sieve. An arrangement of chutes is placed under the machine, in order to sack the meal and grits.

The commercial grades as given by Preuss (16) are:

(a). Superiorware - a high quality product as regards size of granules, and white in color.

(b). Primaware - consisting of other marketable qualities.

The composition of a good,high grade starch, also given by Preuss, is as follows:

Ash	0.24%
Pure Starch	99.18%
Protein	0.28%
Fiber and Fat	0.30%

The Manufacture of Modified Starches and Starch Products.

Not all of the starch as manufactured is used in its original form, but is changed into modified products, which may be classed as follows (17):

1. Those processes in which dry starch is subjected to the action of heat alone, or heat in conjunction with chemical agents.

2. The wet process, in which the starch, suspended in water or cooked to a jelly, is acted upon by chemical agents with or without the employment of heat.

This first process is by far the most important, as nearly all the dextrins and like products are made by this process.

Products made by these methods vary in their physical and chemical properties, depending upon the details of manufacture and chemical agents used. Depending upon the degree of treatment, these products may be white, canary yellow or dark brown, and either insoluble in water, slightly soluble, or entirely soluble. No definite formula for the production of dextrin has been given, and the production may be considered as an art rather than a science.

According to the United States Government Specifications, the practical working properties of a high grade commercial dextrin must be:

Dextrin, by polarization ---------- 88.89%

Reducing substance, as dextrose ---------- 3.62%

Moisture ---------- 2.95%

Ash ---------- 0.12%

Material insoluble in cold H_2O ---------- 0.26%

Polariscope reading, Ventzke scale,

10 gms. in 100 cc. ------ 96.4

Viscosity directly after solution in hot water and cooling to 20 degrees C,

100 gms. dextrin, 200 cc. water-387

Viscosity on standing 24 hours after solution in hot water, 100 gms. dextrin,

200 cc. water -408

Viscosity on standing 24 hours ---------- 412

The viscosity is to be determined with an Engler viscosimeter, and should not materially increase after standing. If the viscosity does increase, it is probably due to a certain amount of free or partly converted starch, and this is undesirable for purposes to which a pure dextrin is placed.

The method for the manufacture of dextrin embraces:

1. Dampening the starch with a hydrolyzing or catalytic substance.

2. Heating between two hundred thirty to four hundred degrees F., until conversion is complete.

3. Removed from roasting oven, rapidly cooled and moistened.

Among the most important hydrolyzing agents are: Hydrochloric Acid, Nitric Acid, Sulphuric Acid, Oxalic Acid, Formic

Acid and Hydrobromic Acid.

Closely related to dextrin is the product British Gum. It has a greater viscosity than dextrin, and its color is usually a number of shades darker. The process of manufacture is essentially the same as that for dextrin, but usually very little hydrolyzing agent is used. The British Gum, as found on the market, usually consists of a combination of several starches.

Another product, known as envelope gum, is found on the market, and exhibits most of the characteristics of dextrin, except it has a much greater viscosity.

Dextrin may also be prepared by the "wet method", in which the starch is cooked to a colloidal paste, hydrochloric acid added, heated and agitated until the starch paste is reduced to a thin liquid. The excess acid is then neutralized, and the solution evaporated to the desired consistency.

Soluble and thin boiling starches come between raw starch and dextrin. These products greatly resemble raw starch, being insoluble in water, giving a blue coloration with iodine, and having about the same granular shape under the microscope. These products are used especially in the sizing and stiffening of cotton fabrics. Their fluidity is high as compared to raw starch, and they give a greater penetration while, at the same time, a much more dense solution may be used. Thus, by using solutions of high content, more stiffness may be imparted to the fabric than is possible with the raw starch.

In the production of vegetable glue, Cassava starch is generally used as the base, although other starches may

be used.

The production usually consists of suspending the starch in two and five tenths to four parts of water, adding a three to five per cent solution of sodium hydroxide and heating, with constant stirring, to the bursting point of the starch granules. A stringy, glue-like mass of high adhesive property is produced.

The Chemical Constitution of Starch.

Although much research has been done on the determination of the constitution of starch, it seems that, even to-day, there is quite a difference of opinion as to the exact structure. By studying the reaction of starch with acids, bases, heat, methylation, Enzymic hydrolysis, bacterial degradation and X rays spectrography, much light has been thrown on the chemical nature of starch but, as these methods are rather involved, it would be impossible to go into these pieces of research in detail; and even if we did, our objective would not have been reached, as they prove nothing definite concerning the molecular construction of the starch molecule. The writer refers the reader to a number of brilliant pieces of research compiled by Walton in his "Comprehensive Survey of Starch Chemistry", Volume I, where these subjects are taken up in detail.

At present, there are two views of the constitution of starch.

First, the view of H. T. Brown and his co-workers (18), who state that starch is a chemical individual of the formula 100 $C_{12}H_{20}O_{10}$, made up of eighty maltan groups, $C_{12}H_{20}O_{10}$, and forty dextrin groups, $C_6H_{10}O_5$, and linked in ring forma-

tion by oxygen atoms.

The second, and probably more accepted view, is that of Maquenne and Roux (19), who state that starch consists of two different substances of which one, amylose, constitutes the internal portion of the starch granule, while the other, amylopectin, forms the external layer. They say that the amylose is completely converted into maltose under the action of malt diastose, and that the amylose is present in starch granules to the extent of eighty per cent in different degrees of hydration and different degrees of solubility, depending on the hydration.

The external portion, which they called amylopectin, is seemingly intermediate between starch and cellulose, and gives a viscous paste upon being heated with water; thus we have the component of the starch granule that is responsible for the pasty or jelly like appearance of a starch solution.

Mme. Gatin-Giuzewska describes two methods of isolating amylopectin by treating starch granules with alkali, where the amylose is dissolved, leaving the amylopectin.

The presence of a non-carbohydrate in starch has been studied by Taylor (20), who states that phosphate phosphorus, silicic acid, and some of the long chain fatty and other organic acids have been found associated with certain starches.

The following table shows the phosphorus content of a few of the common starches as determined by Samec (21), and the associated fatty acids as determined by Taylor and Nelson (22):

	P_2O_5	Fatty Acid by Hydrolysis
Potato	0.112%	None
Meadow Saffron	0.016%	
Arrowroot	0.031%	
Cassava	0.012%	0.12%
Curcuma	0.162%	
Horse-Chestnut	0.016%	0.56%
Wheat	0.105%	
Corn	0.034%	0.61%
Rice	0.039%	0.83%

It has been shown that, when a starch solution ages, the viscosity of the solution decreases and also the variability of the solution by acid and alkali additions. This is thought to be due to the colloidal variation of the dissolved substance by aggregation and coagulation, and a precipitation of some substance responsible for the high viscosity. Therefore amylopectin must have undergone an irreversible change.

A definition for starch that will suffice for this work is: "Starch is the name generally applied to a variety of closely-related compounds which share the common property of conversion, by standard processes, into glucose or maltose respectively, and to each of which the empirical formula $(C_6H_{10}O_5)_x$ may be applied.

The Physical and Chemical Properties of Starch.

Up until the epic discovery of starch sugar by Kirchhoff, about 1811, very little was known about the physical properties of starch, and even less about the chemical properties. After Kirchhoff isolated a sugar from starch, his work

was immediately taken up by other chemists, and a great era of research on the properties and products of starch was begun.

Among the most important works done with starch has been its reaction with acids or hydrolyzing agents to form dextrose and the ultimate product, glucose. A great industry is built up around this reaction, and to-day thousands of tons of starch are yearly converted into glucose and corn syrups.

Pure starch is a perfectly odorless, tasteless, white powder, though commercial starches are sometimes a bit colored; i.e., wheat starches sometimes exhibit a faint greyish tint, and potato starches a faint yellowish tinge, etc. At ordinary temperatures, dry starch is quite stable, and may be heated well over one hundred degrees C. without change but, when heated from one hundred fifty to one hundred sixty degrees C., it begins turning slightly yellow and, upon further application of heat, a substance soluble in water, called dextrin, is formed.

The density of starch varies with the amount of moisture present and, according to Parow (23), the densities in the dry state of some of the more common starches are:

Potato	1.648
Wheat	1.629
Corn	1.623
Rice	1.620

It is seen that the density of the various starches varies in a slight degree only, and this property would not be a suitable method for identifying the different starches.

The refractive indices show only slight differences, varying for the air dry starch, according to E. Ott (24), from 1.504 (Fritillara starch) to 1.529 (tapioca starch; also, the optical activity of the various starches differs only slightly, and may range from $(A)_D$ 201.5 degrees for corn to 204.3 degrees for potato. It is thus seen that these small differences have but little significance, and the above physical properties, quite often used for the identification of other organic compounds, can be of but little value in the identification of starches. Starches can be identified by means of the compound microscope, but this subject will be taken up later under a special heading.

Commercial starches may be neutral, acid or basic according to the method of manufacture, and the care taken in washing and purifying the starch after its separation from the other parts of the plant. It is important to note that, in determining the acid properties of starch, an analysis made by titrating with a standard base would not be correct. The mechanically combined proteins will decompose into amino acids, and these acids exhibit basic as well as acid properties. The true reaction of such starches can, therefore, be established only by a determination of the pH value. The writer has determined this pH value of a number of commercial starches, and the results are tabulated below:

	pH
Corn	6.2
Wheat	7.0
Potato	6.8

Sweet Potato 7.0

Modified Corn 6.8

These readings were taken at room temperature on a solution made by mixing five grams of starch in one hundred cc. of water, allowing the starch to settle, and taking the pH readings of the supernatant liquor. There seems to be a tendency for the values to be from neutral to acid. This acidity could be either from the sulphurous acid used in bleaching or from the combined phosphoric acid content.

Starch is insoluble in cold water and all organic solvents but, if starch is ground in water, the filtered liquid will give the characteristic blue color with an iodine solution. It is not definitely known whether this blue solution is due to dissolved starch or whether, in the grinding, there was enough heat evolved to partly gelatinize the starch or whether some of the small particles came through the filter. According to C. L. Alsberg (25), if natural starch is ground in a pebble mill until most of the granules are injured, the starch becomes incapable of gelatinization at ordinary concentration, and a large proportion of the substance of the starch granules becomes colloidally soluble in cold water. He states that such ground starch yields clear solutions in water at room temperatures which give the iodine coloration, does not reduce Fehlings solution, but dialyses through thin collodion membranes.

If it is admitted that starch consists of a more or less soluble interior portion called amylose, and an insoluble exterior envelope called amylopectin, it may be that this cold

aqueous solution obtained from ground starch is a solution of amylose.

When starch is mixed with hot water, the granules swell and, if heating is continued, finally burst, forming a viscid cloudy liquid known as a starch paste. The temperature at which this phenomenon occurs is known as the gelatinization temperature, and varies with the different starches.

	Start	End
Rice starch	130 F.	176 F.
Corn "	131 F.	168 F.
Wheat "	149 F.	176 F.
Potato "	136 F.	150 F.

The Hydrolysis of Starch.

1. Acid Hydrolysis: When starch is boiled with dilute sulphuric acid, it is converted into glucose and, according to F. Allihn (26), the maximum yield of glucose from starch is obtained by boiling the latter with a two per cent solution of hydrochloric acid for ninety minutes. If a more concentrated acid is used, partial decomposition of the glucose may occur and, even with the more dilute acid, the glucose may decompose if carried on too long. Although it is thought that maltose is formed as an intermediate product, glucose is the sole final product.

There are quite a number of chemical compounds used in the acid hydrolysis of starch, comprising most of the mineral as well as some of the organic acids. It is to be noted that volatile acids are much better for this reaction than non-volatile acids, for they only exert a hydrolyzing effect when

they are in direct contact with the starch granules. When the acid volatilizes, it gives a great increase in surface or volume, and will thus be more effective than the non-volatile class.

In addition to the above mentioned acids, acid salts may be employed in the dextrinitation of starch, or even the neutral salts of certain alkaline-earth bases which, at elevated temperatures, hydrolize into weak bases and strong acids and, in this form, become highly effective hydrolizers. Among the most common salts of this class are the chlorides of magnesium, calcium and aluminum.

In selecting hydrolyzing agents for use in the production of dextrin, care must be exercised to select those less apt to form dextrose, as the presence of this substance in dextrin is undesirable in many cases, one reason for this being that it increases the hygroscopicity of the dextrin.

2. Enzymic Hydrolysis of Starch: The action of an aqueous extract of raw or malted cereal grain on starch was reported first by Kirchoff (11) in about 1815. He states that, if a glutinous constituent is separated from wheat meal by washing and mixed with a paste of potato starch, the pasty stiffness soon disappears and a sugar is formed. The syrup has the sweetness of malt syrup, is fermentable, and is partially soluble in alcohol. He concludes that the formation of sugar in malt is explained, and that a starch-sugar transformation is a necessary step in the alcoholic fermentation of amylaceous materials.

This active principle or enzyme responsible for the

conversion of starch was called "diastase" by the two workers, Biot and Persoz (27). This principle is found widely distributed in various plants and animals, but the pure product has not yet been isolated. It is, therefore, necessary to grade the diastase by its activity. At the present time, all the methods in use for the estimation of diastatic power are based on Kjeldahl's law (28), which he developed by determining the reducing sugar formed by the action of a known amount of malt extract or saliva upon an excess of starch during twenty minutes, at from fifty-seven to fifty nine degrees, and considering that this was directly proportional to the amount of amylose present, so long as digestion was not carried beyond the point which corresponds to a conversion of about forty per cent of the original starch into maltose; and Lintner's soluble starch (29). Lintner recommends, for the preparation of large quantities of soluble starch from raw starch, that the starch be covered with seven and five tenths per cent solution of hydrochloric acid for seven days at ordinary temperature, or three days at forty degrees; then washed free from acid and dried. The starch thus treated does not form a paste, barely reduces Fehling's solution, is easily soluble in hot water, and its solutions remain clear for several days.

In the determination of saccharogenic activity, varying amounts of extract are added to ten test tubes containing equal amounts of starch solution and, after digesting one hour, five cubic centimeters of Fehling's solution is added to each tube, the tubes placed in boiling water, and the first tube noted in which the copper has all been reduc-

ed. The diastatic activity is expressed as one hundred when one tenth cc. of an extract of twenty-five grams of malt with five hundred cc. of water reduces five cc. of Fehling's solution.

Although glucose is sometimes formed in the enzymic hydrolysis of starch, the amounts are generally very small, and the main products are sugar and maltose, together with dextrins of various degrees of complexity, which are themselves converted into maltose on further treatment.

Chlorine appears to have no action on dry starch but, if chlorine gas is passed through a thin paste of starch, the starch is rendered soluble or partly dextrinized. This fact would make the use of common hypochlorites unsuitable for the bleaching of starch in its manufacture.

The reaction between starch and iodine is one of very high importance for, when the two are mixed, even in very dilute solutions, an intense blue coloration is formed, due to the formation of the so called iodide of starch. This reaction is used extensively in chemistry as a qualitative test for either starch or iodine. If a thick paste of the starch is used, the iodide of starch is thrown down as a violet or bluish-black precipitate and, when washed and dried, has a metallic luster. The starch iodide product is only slightly soluble in water.

This blue color of starch iodide disappears in weak solutions upon being heated and reappears upon cooling, but not so strongly as the original color.

This iodine test is also very useful as a method of

control in both the acid and diastatic hydrolysis of starch, since the characteristic blue coloration of starch and soluble starch changes through violet or purple to a reddish brown, and finally to a pale yellowish red, as the hydrolysis progresses.

Much has been written concerning the nature of this starch iodide compound, but opinions are diverse concerning its exact nature.

As has been shown above, most of the mineral and organic acids act as hydrolyzing agents when heated (in small percentages) with starch with the formation of glucose but, under certain circumstances, the esters of the starch may be formed. Thus, Brown and Millar (30) obtained the starch trinitrate with the formula $C_{17}H_{17}O_7(NO_3)_3$.

Some research has been done on starch as a base for the production of nitro-starches for use as explosives, but the product thus formed does not appear to have come into general use, since it is highly hygroscopic and, on account of insufficient purity, is subject to spontaneous combustion.

The sulphuric esters of starch have also been obtained. M. Honig and S. Schubert (31) obtained these esters of the general formula $C_{6n}H_{10n}O_{5n-x}(SO_4)_x$ by grinding starch with concentrated sulphuric acid.

Acetylated starch was prepared by F. Pregl (32) by treating soluble starch with acetic anhydride in the presence of sulphuric acid. He states that, according to the amount of sulphuric acid present, a soluble or an insoluble compound having the composition $C_6H_7O_5-(C_2H_3O)_3$, with a molecular weight

eight or nine times that of the empirical formula; its optical activity is $(A)_D$ equals plus one hundred sixty-three and six tenths degrees, and may be hydrolized with potassium hydroxide to form the soluble starch identical with the original material. The other form, which is insoluble, has the empirical formula $C_6H_7O_5(C_2H_3O)_3$, with a molecular weight three times as large as that indicated by the above formula, with an optical activity of $(A)_D$ equals plus one hundred forty-eight and six tenths degrees and, on hydrolysis, appears to yield an erythrodextrin. This process of acetylation shows that three hydroxyl groups are present for every chain of six carbon atoms, and has thrown some light upon the molecular structure of starch.

The application of the methylation method to starch has not only given results which bear directly on the molecular constitution, but has enabled the acetylation method shown above to be correlated so as to yield a clearer view of the structure.

When a carbohydrate is treated with methylating reagents, the hydroxyls are converted into methoxyl groups and, unlike the acetyl groups, survive the action of hydrolytic agents. A fully methylated starch (trimethyl starch) would, therefore, yield a single trimethyl glucose or, alternately, a mixture of methylated sugars, according as to whether the hydroxyl groups of the parent compound are symmetrically distributed or otherwise. The evidence obtained by the above reactions is very convincing, and helps very much in the study of the molecular structure of starch.

3. Action of Light and Electricity: When subjected to high frequency radiation, starch undergoes more or less hydrolysis. According to L. Massol (33), if a two tenths to a one per cent solution of soluble starch is exposed to ultra-violet rays, the iodine reaction undergoes changes similar to those noticed during the various stages of starch hydrolysis, and the solution also acquires reducing properties. The action of X rays on starch was observed by H. A. Colwell and S. Russ (34). They found that, if a starch solution were exposed to these rays for several hours, there would be a great decrease of opacity and viscosity, the starch being partly converted into soluble starch and dextrin.

W. Lob (35) has shown that a one per cent solution of starch, when subjected to the action of a silent electric discharge for from two to three hours, loses the power of giving a reaction with iodine, and becomes capable of reducing Fehling's solution.

P. Schener (36) was the first to prove that starch gives the X rays spectrum of a crystalline and not an amorphous substance. Owing to the difficulties encountered in this work, very little research has been done, but that which has been done shows that this method may be used to advantage in the study of starch. In the study of most substances, advantage is taken of the fact that the X rays spectrograms show a strong spectrum and the crystals have clear cut definite angles; but when starch is examined by means of the X rays, the spectrum is rather weak, while the rings often become diffused and difficult to measure, and the question as to the identity

of the two substances obtained in different ways becomes difficult to answer. In gelatinization, starch changes into a substance which has a different X rays spectrogram, and the best explanation of these changes seems to be that a chemical change takes place (perhaps the binding of water), or we might possibly assume that the crystalline starches become amorphous.

The Viscosity and Fluidity of Starch Solutions.

The resistance experienced by one portion of a liquid in moving over another portion is called viscosity; or, in other words, the viscosity is the internal friction of the solution.

The fluidity may be defined as the reciprocal of the viscosity.

It has been shown experimentally that the tangential force f, required to maintain a constant difference between the velocities of two parallel layers of liquid moving in the same direction, varies directly with the difference in velocity, v, and the area, A, of the surface of contact of the two layers, and inversely as the distance, d, between the layers; that is, f equals n $\frac{Av}{d}$, where n is a proportionality factor known as the coefficient of viscosity.

The unit of viscosity is the poise, and may be defined as the force necessary to cause two parallel liquid surfaces of unit area and unit distance apart to slide past one another with unit velocity. (37)

The viscosity of a liquid is generally measured by observing the time required for a definite volume of liquid to flow through a standardized capillary tube under a known dif-

ference of pressure and at a known temperature.

The law governing the flow of liquids through capillary tubes was discovered by Poisenille (38), and may be expressed by the equation:

$$n = \frac{\pi P r^4}{8 V l} t$$

where v equals volume of liquid.

n " viscosity of liquid.

l " length of capillary tube.

r " radius of capillary tube.

t " time.

P " pressure.

In the measurements of viscosities, we usually determine the relative viscosity as referred to water, and employ the following equation:

$$\frac{n_1}{l} = \frac{d_1 t_1}{d_w t_w}$$

n_1 equals viscosity of liquid.

d_1 " density of liquid.

t_1 " time of flow of liquid.

d_w " density of water.

t_w " time of flow of water.

When unmodified raw starch is heated with water the individual granules, at first, begin to swell and, as the temperature is increased, the swelling reaches a maximum; in some cases, the granules burst, dispersing throughout the hot water and passing into a colloidal solution.

Alsberg (39) has pointed out that, in the case of wheat starches, the granules do not burst and disintegrate when

boiled, but merely swell without losing their individuality. If this be the case, the physical properties would depend on the size to which the granules swell, and the volume which they occupy as compared to the volume of the liquid in which they are suspended. Due to the mean size of these granules and the degree to which they swell, even if the chemical composition and colloidal properties of two samples are identical, the physical properties, when converted into paste, may be different.

This theory may be true in regard to wheat starch but, in his study of potato starch, the writer has found that the granules seem to burst, and this fact has been substantiated by the loss in viscosity and disappearance of ruptured cells or sacks when viewed under the microscope at intervals during the process. A two per cent solution of potato starch was boiled six hours and the viscosity determined at intervals during the boiling, while slides were made and examined at intervals. It was seen that the envelopes surrounding the starch granules seemed to burst and, after prolonged boiling, to go into a colloidal solution. As can be seen by looking at the experimental part of this report, the viscosity of the potato starch paste suffered to a great extent on prolonged boiling. (See curve.)

Thus the viscosity or internal friction may be said to be due to larger particle size, and the individual particles of starch have not been divided and dispersed to single molecular particles. These dissolved particles may be present as aggregates, and sometimes as irregular aggregations which

build up into structural forms and, therefore, cause greater internal friction. The molecular aggregates may grow to increased dimensions with changes in density, temperature, pH and electric charge.

Ermen (40) has called attention to the presence of the starch envelopes after the granules have burst, and states that these have a marked effect on the viscosity of the solution. He says that these particles are very fragile, and that it is impossible to get concordant results when the same starch solutions are passed back through the viscosimeter for, when the solutions are re-heated, agitated and poured, more of these sacs are broken down and the viscosity is thereby lowered. Thus, in order to get a starch solution of any degree of stability, it is necessary to subject it to prolonged boiling and agitation to break up most of these skeletal forms.

Due to the loss in viscosity of potato starch solutions on prolonged boiling, it is thought by some that its sizing properties have been destroyed, but it has been shown that, if a greater concentration of the starch is used initially, the viscosity will hold up better and the sizing properties are even improved over those of other starches in certain respects.

Viscosity also changes with change in temperature. This involves not only the higher viscosity, due to the lowering of the temperature, but also a change of viscosity due to part of the starch coming out of solution. A sustained temperature is, therefore, of the highest importance in producing a size solution of uniform viscosity and, in turn, a uniform distribution of the size on the yarn.

The penetration of the size, whether by capillary action, forced by pressure or voluntary, is dependant on the viscosity and, if we vary the viscosity, we vary the penetration.

The adhesiveness of a substance depends upon the character of the solution, and the effectiveness upon its distribution; viscosity is a determining factor in both cases.

Those substances which form continuous films give greater strength when used for adhesives, and greater suppleness and smoothness when used as a fabric finish. Continuous films are not formed by crystallizable substances; therefore, the more truly colloidal a solution, the greater the adhesive properties and the greater the film forming properties.

The degree to which a starch forms a truly colloidal solution rather than a suspension is dependant upon the different kinds of starch used, the methods of treatment and the time employed. It is to be noted that a colloidal solution differs from a suspension only by the size of the suspended particles. If the particles are melecularly dispersed throughout the solvent, it is a true solution; if the particles dispersed throughout the solvent are relatively large in size, it is called a suspension. At an intermediate stage between that of a true solution and a suspension, we have what we call the colloidal state. Thus it may be seen that a starch solution may be in any one of these three states.

It is thought by some that the starch granule is composed of two parts; an internal part called amylose, which forms a colloidal solution, and may embody eighty per cent

of the starch granule; and an external part called amylopectin, which at first forms a suspension and probably, after prolonged boiling and agitation, a colloidal solution.

It is thought that the viscosity of a starch solution is due to this last mentioned substance, amylopectin. Thus a starch solution may be partly a colloidal solution and partly a suspension.

The degree of dispersion and a minimum of undissolved matter appear to be of great importance in the formation of a continuous film (41).

The advantages of starches are that even in their raw state they form viscous solutions of a higher density than the natural gums such as agar, Irish moss and locust bean, and that by use of modified starches we may still further increase the density of the solutions without increasing the viscosity. Solutions of starches carrying twenty to thirty times as much solid matter as the natural gums may be prepared, and have a viscosity suitable for sizing purposes.

Since the density of starch solutions may be made relatively great and since the adhesive properties and thickness of the film formed depend on the density, it is clearly seen that there will be a resultant increase in adhesive bond and stiffness of the material treated.

In determining the viscosity of a starch solution, there are two methods in general use. The first is to make up the starch paste with the proper amount of water and heating until the granules are dissolved or dispersed and the viscosity determined in any one of the standard types of viscosimeters.

The second method consists of the use of sodium hydroxide for the gelatinization of the starch, carrying out the process at room temperatures. Since the viscosities are usually relative and carried out on the two or more samples at the same time, either of these methods should give the desired results, but it seems that the first method more nearly follows the practical application and, for this reason, should be the better of the two.

It should be remembered that the viscosity of a starch solution is altered by many factors, and it is almost impossible for any two workers to exactly check each other on the absolute viscosities of any starch solution, but the relative velocities found by any one worker may be of great help in the study of starch.

The Application and Uses of Starch in the Textile Industry.

The use of starch in the textile industry may be discussed under three heads:

1. For use as a filler or stiffener in the printing of textile fabrics with certain types of dyes. Here the starch simply gives the color solution enough viscosity or body to prevent its "running" on the fabrics and marring the design or effect desired.

2. As a filler or stiffner in certain types of fabric finishing. Certain grades of loosely woven materials are made for the export trade and require a stiffner and filler to increase their weight and make them appear to have the qualities of a more expensive fabric while other fabrics, requiring certain special finishes, are obtained by finishing them with

starches and other suitable agents.

3. The use that will be taken up in more detail in this paper will be that in which yarn is prepared or sized before going to the looms or weaving rooms.

The matter of sizing yarns has not been generally taken very seriously in the textile mills of the United States and, for this reason, much trouble and inconvenience has been encountered in the weave room which could have been partly avoided had more care been exercised.

No matter how efficient the superintendent and foremen may be in the spinning, no matter how much time and energy may be spent in turning out a perfect yarn, if it is improperly sized and the weaver has trouble with broken ends, all this work is lost. As mills are beginning to see, the whole production of the plant hinges more or less around the slashing room.

Yarns, as they come from the spinning room or warper, are too weak to stand the chafing and tensile strain to which they are subjected in the weaving room. The individual fibers are more or less loosely twisted together,and the surface of the yarn has individual fibers protruding in all directions ready to catch on any adjacent object and cause a weak place in the yarn. This friction between the yarn and other adjacent objects, such as the harness and reed, might be materially cut down if the surface of the yarn were smooth. This is one of the objects of sizing as shown below.

The objects of applying a size mixture to cotton yarn are:

(a). To bind the loose fibers.

(b). To strengthen the yarn.

Starch used as a surface sizing fills voids between fibers, decreases porosity and adds weight; it also serves as an adhesive surface which tends to hold down the projecting surface fibers; in fact, the strengthening effect of starch on yarn is chiefly dependent on the strength of the starch film itself. S. M. Neale (42) has shown that starch films behave very much like ductile metal, such as copper, on loading and unloading, and that there is scarcely any difference between the elastic properties of corn, potato and sago starches, but that the films are harder and more brittle in dry than in moist air.

When the cotton yarn is passed through the starch solution, a film is formed on the surface, and this film aids materially in the manufacturing process by resisting abrasion. Truss effects are made possible by continuity of film and, in turn, the greatest gain in strength.

There are two factors involved in the sizing of cotton yarn. As stated above, we must have good penetration of the size in order to fill up the cavities between the individual fibers, and we must have a solution with enough viscosity to lay the protruding surface fibers. It seems at first that these two factors counteract each other for, as the viscosity increases, the property of laying the fibers increases, while the penetration decreases. It is here that the modified starches come in. There seems to be a certain viscosity at which the two above mentioned factors are at a maximum, and it is up to

the finisher to work these values out in his own plant.

A size that congeals slowly will remain fluid for a longer time at temperatures below boiling. As the yarn passes from the boiling size box to the squeeze rolls, there is a considerable drop in temperature. It is important that the starch solution does not congeal before it passes through these rolls, for it is here that the maximum penetration is obtained. This property of slow congealing is natural to some starches, such as wheat, potato and tapioca, but not so much much so for corn starch (41).

Some starches, when of sufficient viscosity and density for sizing, lose their fluidity and set to a jell when the temperature drops from a boil to one hundred eighty or even one hundred sixty degrees F., while other starches, at the same concentration, will remain fluid even if the temperature is dropped to from one hundred fifty to one hundred thirty degrees F.

The best sizing results are obtained with slow congealing starches. This property of slow congealing is inherent to modified starches, and is one of the reasons for their growing popularity. As mentioned above, potato starch is classed among the slow congealing starches, and it held a place for itself as a size for difficult weaves until the development of modified corn and wheat starches.

The matter of thin boiling and slow congealing starches has been mentioned above, and it would seem at first that a method of treating starch in the size kettle to render it more fluid would be economical from the standpoint of the finisher.

The addition of an acid to the size kettle would cause thinning or partial conversion of the starch, and the addition of alkali would cause an increase in viscosity, due to a further solution of the amylopectin; but methods of this nature seem to be very difficult to control, as the action of the chemicals are very rapid at the elevated temperatures and different lots of even the same brand of starch require different amounts of chemicals. It is understood by the writer that some mills are employing the use of chemicals in the size kettle to modify their size mixture, probably by the addition of acetic acid; but these methods require very close control, and the services of a well trained technician. It seems that the use of acetic acid could be controlled by running the mixture at temperatures below the boil until sufficient thinning has been obtained, and then raising the temperature to a boil, which will drive off the volatile acid and stop the conversion.

Even a partial list of the various materials recommended for use in size would count up to over one hundred, but the necessary ingredients for a size may be tabulated as:

1. The adhesive element (starch).
2. Greases or softeners (tallow, etc.).
3. Hygroscopic substances ($CaCl_2$, etc).
4. Antiseptics (salicylic acid, etc.).
5. Weighting material.
6. Water.

The properly prepared size penetrates the fibers, leaves a continuous uniform film over the surface, and holds the fibers together. This increases the strength of the yarn, for dry un-

treated yarn is held together only by the twist of the fibers around each other while the size, upon drying, actually cements these fibers together so that, in addition to the strength produced by twist, there is an added strength due to the starch itself.

Starch of itself will dry into a hard brittle film and thus render the yarn unsuitable for weaving. This effect is counteracted by the addition of a softener or sizing assistant to the size. This assistant should have perfect penetrating properties, and should blend with the starch and produce the necessary softening without materially affecting the body or adhesiveness of the starch.

Tallows, fats and oils have very valuable softening properties. It is to be noted that the quality and adaptability of a softener for this purpose is neither indicated nor in direct proportion to its saponifiable content (44).

Often softeners are made up and sold containing large amounts of starch, dextrin, etc., as fillers. The purchaser pays for these cheaper products at the rate of the higher constituents. It seems that it would usually be more economical to buy the pure tallow and oils and make up the softener in the proportions desired.

Magnesium and calcium chloride are used rather extensively in sizing compounds since they are deliquescent and take up quantities of water from the atmosphere. An elaborate system of humidifying is necessary in the weave room to keep the yarn moist enough, so that it will run properly through the loom, and it seems that a substance that will of itself take up mois-

ture from the atmosphere would be highly beneficial. It is known that at high temperatures the chlorides of magnesium and calcium will break down and forms acids, which might be injurious to the cotton fabric. According to the research staff of E. F. Houghton and Company, this danger of weakening the yarn overbalances the advantages derived from the extra moisture taken up by the chloride; thus, by examining one sizing compound, it was found that the chlorides totaled twelve per cent of the mixture. If we assume a size mixture made up with it containing two hundred pounds of starch, twenty-five pounds of sizing compound and made up to two hundred gallons, then, on the basis of twelve per cent, there would actually be put into the size twelve per cent of twenty-five pounds, or three pounds of chlorides. This size mixture is sufficient to size two thousand pounds of soft yarn; then, if the three pounds of chlorides would absorb three pounds of water, this would increase the weight of the yarn by only fifteen ten thousandths per cent, which would be negligible as compared to the percentages of moisture taken up and given off with only slight changes in relative humidity of the weave room.

Paraffin wax is sometimes used in the size compound, but this is to be discouraged except in the application to very low grades of materials, because this wax is very difficult to remove, and may show up in the finished fabric as light spots or specks.

It is a common practice in some slasher rooms to drive off the total moisture from the yarn as it passes over the dry-

ing cans, and more or less bake the yarn; then when the yarn is carried to the weave room, an attempt is made to restore this moisture content by the use of very high humidities, which sometimes place so much moisture in the yarn that there is an increased danger of mildew; also, the yarn is never brought back to its original soft condition. It is a much better practice to so control the heating of the cylinders that about eight to ten per cent moisture is left in the yarn as it leaves the slasher.

There seems to be another fallacy in common practice in calculating the load of sized yarn by comparing the net weight of the sized yarn as delivered on the loom beam at the slasher with the weight of the yarn before slashing. The increase in weight so calculated is taken as the load or weight of starch added. If the moisture content of the sized and unsized yarn were the same, this method would be correct; but the moisture content varies to a considerable degree, and it is necessary to use a chemical analysis to determine this weight.

Standard methods have been worked out by means of which the starch is removed from the yarn by enzymic hydrolysis or acid hydrolysis. By taking the bone dry weight of the sized yarn and subtracting from this the bone dry weight of the desized yarn, the weight of size added can be calculated.

One of the things a finisher has to watch is the formation of mildew in his warps after they have left the slasher and are stored, prior to being transported to the weave room. With perfectly dry warps there is no danger of mildew, but as warps usually contain from eight to ten per cent moisture,

there is danger, and precautions must be taken against this by making additions of a fungicide to the size kettle.

There are very few fungicides entirely suitable as preventives of mildew. Among the best are probably thymol, resorcinol, naphthalene, Beta naphthol, benzoate of soda, zinc chloride, salicylic acid and cresol.

In America, corn starch is probably the most generally used by textile plants. In using this starch, thorough boiling is required in the preparation of the solution, or else penetration will be very poor, and we will have what is called "dusting off" as the yarn passes through the looms.

Corn starch has become of much more importance with the advent of modified starches. According to Bean (43), wheat flour is most generally used in England in the preparation of size. He states that it is capable of adding as much as forty per cent to the weight of the yarn without the use of mineral matter or loss of weaving properties.

Potato starch seems to be next in importance to wheat flour for sizing, and is used chiefly for sizing goods of light reed and pick, giving for this class of work a smoothness and pliability to yarn which is not excelled by any other starch. Potato starch loses its viscosity and adhesive power on protracted heating, but retains these properties if treated with small proportions of NaOH at temperatures under a boil.

Sago starch is chiefly used in pure sizing. It strengthens the yarn more than any other starch used in sizing, and stands prolonged boiling without losing strength. It requires being well boiled, though less boiling will suffice if a small

quantity of sodium hydroxide or potassium hydroxide is used in mixing.

Bean (45) states that tapioca starch is not often used in sizing except for very light goods where a soft "feel" is desired, or in conjunction with corn to take the place of potato.

Starch in the Finishing of Cotton Fabrics:

As has been mentioned above, starch, soluble starch and dextrin are also used in the process of finishing cotton fabrics. The starches chiefly used for this work are corn, wheat, potato, cassava and rice.

The general procedure in preparing the starch mixture consists of heating a well stirred mixture of starch, mineral filler, etc., with water until the starch gelatinizes. The starch imparts stiffness to the cloth, prevents the filler dusting off, and gives the fabric a gloss when it is run through the calendering process.

Soluble starch or dextrin should be used on those fabrics which are to remain in a more or less soft condition after finishing. They produce a gloss on the fabric upon being calendered just as the raw starch does.

The Use of Starch in Laundry Work.

Starch is used in laundry and household work for dressing and finishing fabrics after washing. The starches commonly used are corn, wheat, sago and rice. In order to obtain the highly glazed surfaces required for collars, etc., the starch is mixed with a preparation known as starch glaze or starch gloss, which may consist of borax or a mixture of vari-

ous materials, including borax.

These materials may include French chalk, soap, stearin, white wax, paraffin wax, spermaceti, gum Arabic, gum tragacanth, dextrin and glycerol. According to S. B. Chambers (46), a typical preparation may consist of:

100 pounds dry corn starch.
15 ounces powdered borax.
6 " nitric acid.
6 gallons water.

The ingredients are mixed, allowed to stand from twenty-four to forty-eight hours with occasional stirring to prevent overheating, and then dried.

Other Uses for Starch.

Starch is also used in other processes. One of the first uses for starch was in the preparation of papyrus to prevent the absorption of ink. Today it is used as an agent to harden and stiffen the surface, improve the appearance of the surface, and to paste sheets or layers of paper together.

Starch is also used in the leather industry as a vehicle for the tanning extract in drum tanning.

The confectionery trade uses quantities of starch in making custard powders, cake mixtures, patent grade wheat flours and ice cream powders.

Starch is used to some extent in the pharmaceutical industry as an ingredient in dusting powders, face powders, cosmetic creams and pomades.

The Identification of Starches by Means of the Microscope.

As has been shown above, many of the methods for identifying organic substances, such as determination of density, index of refraction, optical activity and X ray spectrograms, are found unsuitable when dealing with starches, as the values found for the various starches are so near the same that differentiation would be very difficult.

By the use of the microscope, it is usually possible to distinguish between the different starches. By the help of pictorial drawings and verbal descriptions, much light may be thrown upon the subject, but it is always a good plan to keep samples of the various starches on hand, so that direct comparison may be made.

The characteristics to be observed when examining a sample of starch are:

1. Size of granules.
2. Nature of compound granules present.
3. Shape of granules.
4. Position and appearance of hilum or organic center.
5. Striae, or markings around hilum.
6. Appearance of granules in polarized light.

1. In determining the size of the granules, measurement is usually made along the longest axis and the results expressed in microns (U), one micron being equal to ten to the minus seven power centimeters. The size of the granules for the same sample of starch varies between wide limits. Some granules, such as those from canna, are nearly all large; others, such as those from rice, are nearly all small; still others, such as potato, have both large and small granules.

2. When considering the nature of the compound granules, it is seen that they may consist of simple or aggregate granules, or even both kinds in the same sample.

Compound granules may consist of from two to several hundred component parts, but these are usually more or less broken up in the process of extracting the granules from the other parts of the plant; so, to obtain the more perfect specimen, it is necessary to examine the undisturbed starch of the plant.

3. When examining the shape of the starch granules, it is seen that there is a great diversity of form; thus there can be no scheme or classification altogether free from objection. Upon examination of the different starches, the following classes may be distinguished, though some granules may be of shapes intermediate between those as classified (47):

1. Round.
2. Lenticular.
3. Elliptical.
4. Oval.
5. Truncated.
6. Polygonal.

Care should be exercised in examining and classifying the shapes of the granules as, for instance, elliptical granules may appear round when viewed in certain positions. This may be overcome by slightly changing the position of the starch granule in question. Truncated or kettle-drum shaped granules are component granules which have been broken apart from a

compound granule and the flat sides are the surfaces of contact in the compound granule; thus, component granules from a larger aggregate may be polygonal in shape. In almost every sample of starch, there are some granules which may differ entirely from the rest so that, in the identification, it should be remembered that the majority of the granules determine the shape.

4. The hilum is the organic center around which the starch granule has grown, and may be placed either concentrically or eccentrically in regard to the general shape of the granule.

The hilum is very noticeable in some starches, while in others it can hardly be seen. It is quite large in some cases, and very small in others. The hilum appears to contain more water and be softer than the material sorrounding it and, upon drying, tends to wrinkle and appear starred with fissures.

5. Placed around the hilum are striae, or markings in a concentric position. These markings vary from very noticeable to very faint ones and, in some cases, there appear to be none at all. This property is better brought out by means of oblique illumination, and by treatment with dilute chromic acid solutions.

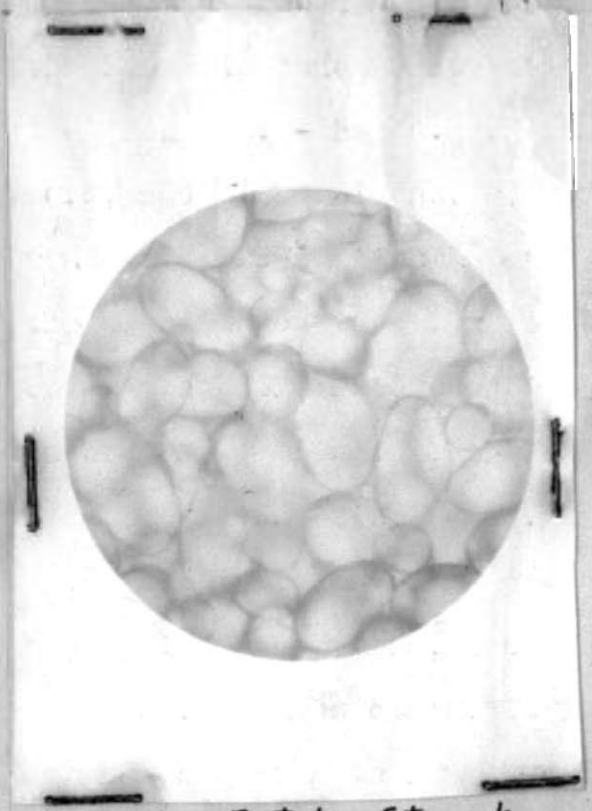
6. When starch granules are observed through a polarizing microscope, they appear brightly illuminated against a dark background, and exhibit a black cross.

The point of intersection of the arms of the cross coincides with the position of the hilum, and is a useful

aid in locating the hilum when it is difficult to see. If the hilum is concentric, the cross is X-shaped; if eccentric, the cross is V-shaped. This cross appears to be due to pressure, and W. Harrison (48) pointed out that the cross was rendered more distinct by moistening the dry starch, due to the swelling of the granule and an increase in internal pressure. When the outer coating of the granule (amylopectin) is broken by grinding, the internal pressure is released and the black cross disappears.

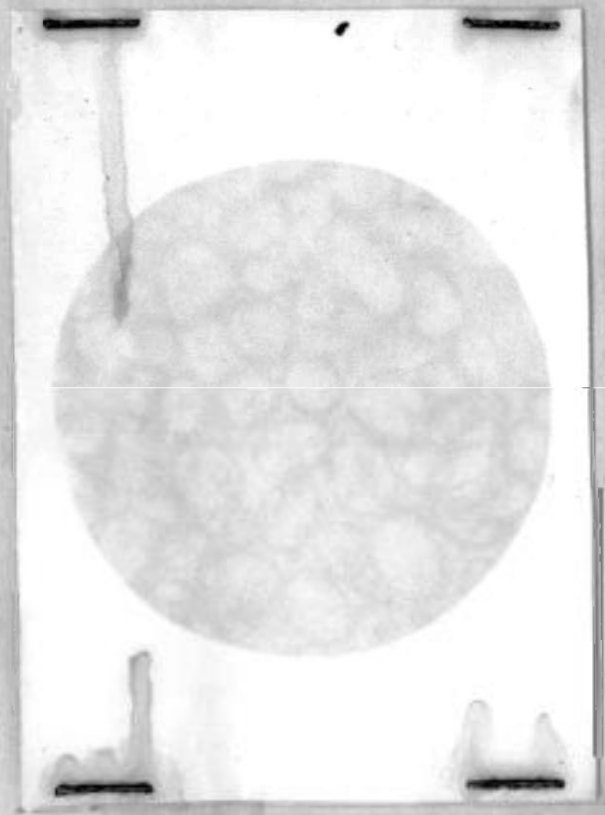
When starch from more than one source is found in a sample to be examined, the detection is rendered very difficult but, in some cases, it is possible to distinguish them.

According to a method proposed by K. Baumann (49), it is possible to detect the presence of corn starch in wheat meal by mixing about one tenth gram of the meal with ten cc. of a one and eight tenths per cent solution of potassium hydroxide, shaking the mixture at intervals during two minutes. The mixture is then treated with from four to five drops of HCl of twenty-five per cent concentration, and again shaken. It is necessary that the liquid should remain alkaline, since the protein will precipitate in an acid solution and interfere with the subsequent microscopical examination. If a sample of the mixture is now examined under the microscope, it will be seen that the wheat starch granules are completely ruptured, while the corn starch remains unaltered. A rough estimate of the proportions of the two starches may be obtained by comparison with known mixtures of these two starches made up in this way. This method may



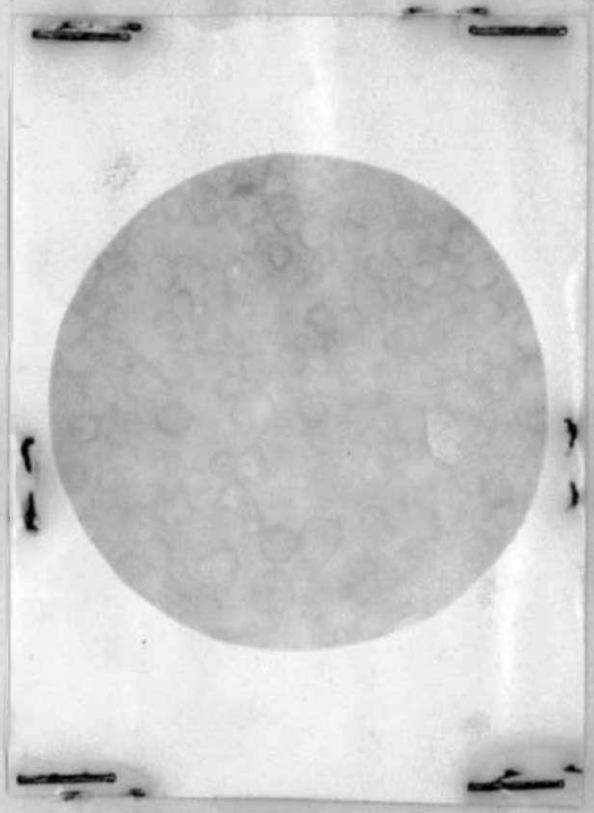
White Potato Starch
X500

Sweet Potato Starch
X500

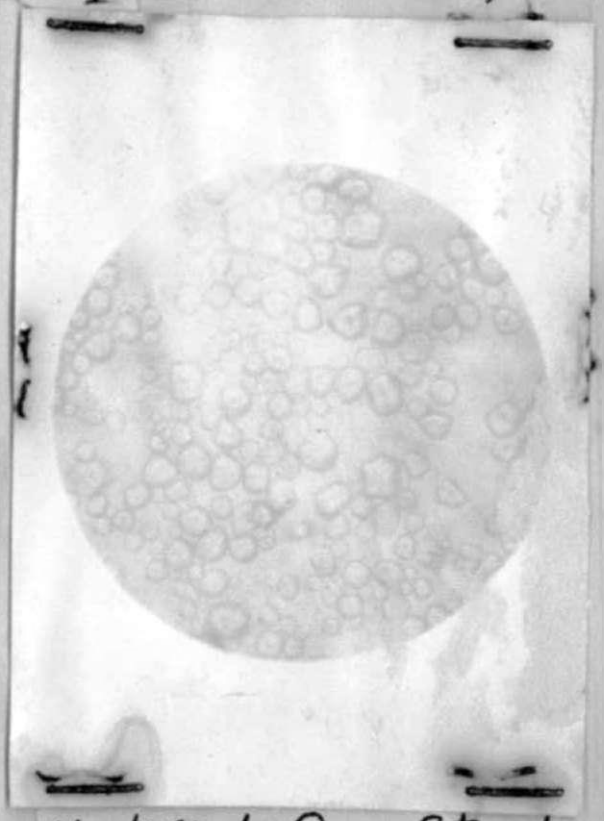


Sago Flour
X500

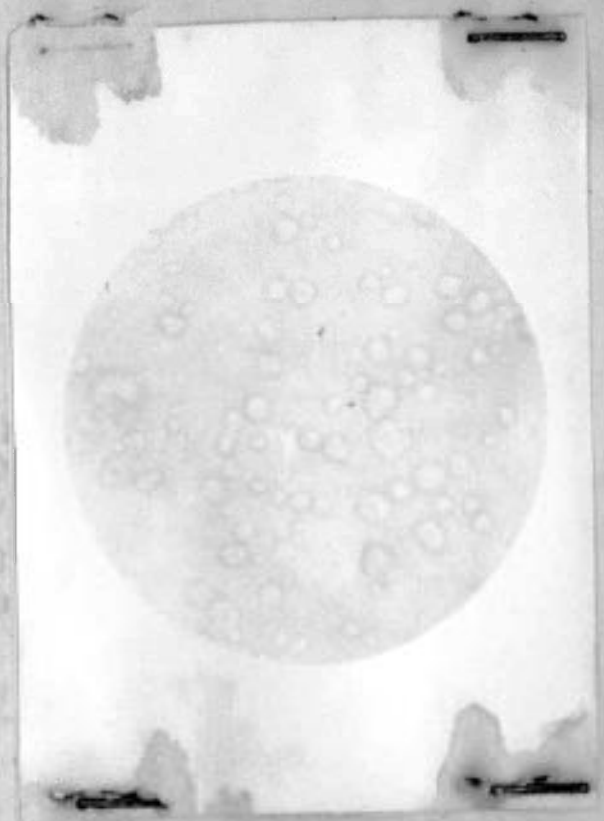
Rice Flour
X500



Corn Starch
X500



Modified Corn Starch
X500



Corn "Gum" Starch
X500

be used also in the detection of corn starch in rye meal, the granules of the rye being ruptured even more rapidly than the wheat.

Many methods have been proposed for the identification of starches in mixtures, but enough difficulties are encountered in the identification of single starches, and these methods are not used very extensively.

Analysis of Starch.

The analysis of commercial starches consists of an estimation of the water, mineral matter, protein, starch, and occasionally,fat and fiber present. In the case of commercial starches, the percentage of starch in a sample may be calculated by determining the percentage of other materials present and subtracting this from one hundred per cent, but in case of the determination of starch in other materials, it is necessary to convert the starch and make the determination by optical activity or reducing properties.

Starch may contain from thirteen to twenty per cent moisture. This may be determined by direct heating of the starch, but care must be taken in this operation, as the starch is apt to partly gelatinize at temperatures high enough to drive off all the moisture. It is customary to drive off the bulk of the water at lower temperatures,from around forty-five to fifty degrees C., and then raise the temperature to around one hundred twenty degrees C to drive off the remainder.

The mineral matter present in starch may be determined by igniting a sample in a platinum or porcelain crucible until

the residue is white or light grey. Commercial starches contain an average of about thirteen hundredths per cent mineral matter.

The fat content may be determined by extraction with ether in a Soxhlet extractor. This constituent is usually very small.

Much research has been done on the determination of starch in other materials, and most of the methods consist of more or less hydrolyzing the starch and determining the starch by copper reduction or polarimetrically.

The method of direct acid hydrolysis as adopted by the Department of Agriculture is given below, but it has this disadvantage. Any pentosans or other carbohydrates that undergo hydrolysis on treatment with acid will be included in the determination.

Stir from two and a half to three grams of the material in a beaker with fifty cc. of cold water for one hour; then filter and wash with two hundred fifty cc. cold water. The residue is heated two and one half hours with two hundred cc. of water and twenty cc. of dilute hydrochloric acid (S.G. 1.125) in a flask with a reflux condenser. The solution is then cooled, nearly neutralized with sodium hydroxide, and made up to two hundred fifty cc. An aliquot part of the filtrate is then used for the determination of the dextrose. The dextrose times nine tenths gives the weight of the starch.

A more accurate method has been proposed by H. T. Brown (50) in the determination of starch in barley and malt. About five grams of finely ground material is extracted with

eighty cc. of alcohol (S.G. 0.920) in a Soxhlet extractor for three hours, in the case of barley, and nine hours, in the case of malt. This removes the reducing substances and alcohol soluble nitrogen compounds.

The contents are then transferred to a beaker containing one hundred cc. of water, and thoroughly boiled; then cooled to fifty-seven degrees C. and treated with ten cc. of active malt extract. The extract is prepared by extracting one hundred grams of finely ground malt (diastatic power eighty on the Lintner scale) with two hundred fifty cc. water at from fifteen to twenty degrees C. for two hours, and filtering.

The conversion is allowed to proceed at fifty-seven degrees C. for one hour. The solution is then boiled, filtered into a two hundred cc. flask, the residue well washed, and the filtrate made up to two hundred cc. The maltose content of an aliquot part is then determined by one of the regular methods as given below. A correction must be made for the reducing power of the malt extract employed. After determining the maltose present, the equivalent starch may be calculated from the equation

$$10C_{12}H_{20}O_{10} + 8\,H_2O = 8C_{12}H_{22}O_{11} + 2C_{12}H_{20}O_{10},$$

Starch — Water — Maltose — Stable Dextrin

according to which eighty four and four tenths parts of maltose correspond to one hundred parts of starch.

Polarimetric Method:

A method proposed by C. J. Lintner (51) for the estima-

tion of starch in barley is as follows:

Five grams of finely ground powder are mixed with twenty cc. of water and stirred until no lumps are left. This is then mixed with forty cc. of concentrated hydrochloric acid (S.G. 1.19) and allowed to stand thirty minutes. The material is thus converted into a dark colored mobile liquid. This solution is now rinsed into a two hundred cc. flask with hydrochloric acid (S.G. 1.125) and treated with ten cc. of a four per cent solution of phosphotungstic acid and made up to two hundred cc. with hydrochloric acid (S.G. 1.125). The solution is then filtered and the angular rotation determined by use of the polariscope.

The starch content of barley is calculated on the assumption that barley starch dissolved in hydrochloric acid under prescribed conditions has a rotating power at twenty degrees C. under sodium light of two hundred and three tenths degrees. The amount of starch in the sample is found from the formula: % equals $\frac{4000\ A}{l\ (A)_D}$

A equals observed angle of rotation.

l " length of polarization tube in decimeters.

$(A)_D$ equals specific rotatory power of barley starch under given conditions.

Analysis of Starch Dextrins:

Dextrins are produced from raw starch by either heating with acids or without acids. The products obtained with acids are generally white or a light cream color, while those produced without acids are generally of a brownish color.

The dark colored dextrins are usually soluble in both hot and cold water, but the white dextrin is somewhat insoluble in cold water.

The structure of the starch granules is very little changed during the dextrination process, and the method for detection under the microscope can be used here as on raw starch.

Dextrin usually has a moisture content of from eight to ten per cent, and this may be determined by direct heating. The acidity may be determined by titration with standard sodium hydroxide.

The following method by F. Lippmann (52) is a method for determining the portion of dextrin soluble in cold water.

Twenty grams of the sample are treated with two hundred cc. of water in a five hundred cc. flask, tightly stoppered and vigorously shaken for five minutes. The solution is then filtered and the density of the filtrate determined with a Brix hydrometer. The reading times ten is equal to the per cent of the portion soluble in water. The portion soluble in cold water will be one hundred minus the per cent soluble in hot water.

The iodine reaction affords some guidance in determining the degree of dextrinization of starch, and O. Saare (53) proposes the following procedure for factory control.

One tenth of one gram of the sample is mixed with five cc. of water in a large test tube marked at one hundred cc. and heated until the material is dissolved. It is then diluted to one hundred cc. and the solution treated with one

drop of N/10 iodine solution. The colors produced as the drop falls and after shaking are noted; then by making up a standard table of the color changes, a rough estimate of the degree of dextrinization can be determined.

Analysis of Starch Sugar.

By the term "starch sugar" we mean the glucoses of various qualities such as pure dextrose, solid glucose or grape sugar. It may also contain traces of maltose, dextrin, protein, mineral matter and water.

The full analysis of a starch sugar or syrup includes the estimation of dextrose, maltose, protein, mineral matter and water. The unfermentable matter may be found by difference.

In commercial glucoses the dextrin may range from fifty to seventy-five per cent; maltose from two to twelve per cent; mineral matter from five tenths to two per cent; and protein from two tenths to two per cent (54).

The water in starch sugars may be determined by direct heating, but in the case of the syrup the solution density method must be used.

The ash content is determined by igniting in the presence of sulphuric acid and subtracting ten per cent for sulphating.

The percentages of dextrose, maltose and unfermentable matter may be estimated by the method proposed by G. H. Morris (55). It consists of diluting ten cc. of a ten per cent solution of the sample to fifty cc., and using ten cc. of this for the determination of the reducing power by the Brown,

Morris and Millar's method (56).

Fifty cc. of Fehling's solution are transferred to a flask of two hundred fifty cc. capacity, covered and placed on water bath for a few minutes. The sample is then added, the solution made up to one hundred cc. with boiling water, heated twelve minutes and the precipitated copper oxide filtered, washed, dried and finally weighed. This weight times five hundred will give the copper equivalent to one hundred grams of the sample.

A second portion of the ten per cent solution of the sample is read in a two hundred mm. tube in terms of Ventzke saccharimeter degrees.

A third portion (fifty cc.) of the ten per cent solution is used for the determination of the copper-reducing power and optical activity of the unfermentable matter. This solution is boiled a few minutes, fermented, treated with a little alumina cream, made up to one hundred cc., filtered and the reducing power and Ventzke reading of filtrate determined.

The percentage of dextrose and maltose is now calculated as follows:

The weight of copper oxide before fermentation minus the weight of copper oxide after fermenting represents the dextrose and maltose in one hundred grams of the sample.

Again the Ventzke reading of fermented solution is deducted from that of the ten per cent solution before fermentation, and the remainder in Ventzke degrees, due to dextrin and maltose, is converted into $(A)_D$ by:

$$(A)_D \text{ equals } \frac{V \times 10}{2} \times 0.346$$

If D is the percentage of dextrose, and

M " " " " maltose, then

MD plus PM equals a (1).

a equals CuO equivalent corresponding to dextrose and maltose in one hundred gm. sample.

M equals CuO equivalent in 1 gm. dextrose.

P " " " " 1 " maltose.

M and P are to be read from tables compiled by Brown, Morris and Millar (56).

Then if the value of $(A)_D$ is denoted by "b":

52.7 D plus 138 M equals b plus 100 (2).

D and M can then be calculated by equations (1) and (2).

Experimental.

In making up the starch solutions, it was first necessary to determine the per cent of moisture in the different starches, so that this might be taken into account when making weighings. The method of determining the moisture was to weigh out approximately ten gram samples of each of the starches, place in an oven at fifty degrees centigrade for one hour, then raise temperature to one hundred twenty degrees C. for five hours, and then weigh again. The difference is the amount of moisture in the starch. It will be noted from the following data that the percentage of moisture is rather low, but this was probably due to the fact that the starch had been stored for some time in a warm steam heated room.

Table #1.

Starch	% Moisture
Corn	8.49%
Wheat	9.18%
Potato	12.81%
Sweet Potato	28.8%
Tapioca	9.46%
Rice	8.72%
Sago	10.47%
Modified Corn	16.8%

The apparatus used in determining the viscosities of the different starch solutions consisted of a glass funnel with a small nipple attached by means of a short piece of rubber hose. This glass funnel was placed in a constant

temperature copper funnel by means of which the temperature of the solution being tested could be regulated. A thermometer was suspended over the funnel and extended into the starch solution. A one hundred cc. graduate was used to catch the solution. The time taken for fifty cc. of the solution to flow through the funnel was determined with a stop watch.

Test number one was made to determine the change in viscosity with time of boiling. The solutions were made up with a concentration of two grams of starch to one cc. of solution. The starch solution was gradually brought to a boil and kept there the desired length of time. The solution was then poured into the funnel, and the time required for fifty cc. to flow at two hundred degrees F. determined. The following tabulation shows the results obtained:

Table #2.

Solution	Viscosity 30 Minutes	Viscosity 1 Hour	Viscosity 2 Hours	Viscosity 4 Hours	Viscosity 6 Hours
Corn	43	43	42.2	39.6	38.2
Wheat	42.36	42.46	41.60	41.2	39.83
Potato	88.0	70.5	58.8	48.5	42.9
Rice Flour	39.1	39.7	39.1	39.6	40.0
Sweet Potato	46.4	47.4	47.7	43.6	43.6
Sago	41.0	40.0	40.0	39.6	38.7
Tapioca	49.3	51.9	49.9	42.6	40.03
Water	37.6				

Figures one to seven, inclusive, show this data plotted as viscosity against time. Although the vertical scale is labeled "Viscosity", it is really "Time of Flow"; but it

answers our purpose, as it shows the relative change in viscosity with time.

It may be seen that all of the starches studied lose in viscosity with prolonged boiling, with the exception of rice flour, Figure 6. This is probably due to the fact that rice is difficult to get into solution, and will take this length of time to get gelatinized. The greatest change is noted in the case of white potato starch, Figure 3, which loses about fifty per cent of its viscosity upon being boiled six hours. Sweet potato, Figure 4, and tapioca, Figure 5, show similar curves, but the tapioca comes to a maximum before the sweet potato. Corn, Figure 1, and wheat, Figure 2, show some similarities, while sago, Figure 7, seems to hold its viscosity nearly to the end of the boil. The high viscosity after thirty minutes boil was probably due to ungelatinized particles obstructing the flow and making the viscosity appear higher.

The second test carried out was a study of the various starches under different degrees of temperature. These were also two per cent solutions, and the following data shows the time in seconds for fifty cc. of the solution to flow through the funnel at one hundred forty degrees F.

Table #3.

Solutions	Viscosity 140 F.	Viscosity 160 F.	Viscosity 180 F.	Viscosity 200 F.	Viscosity Boil
Corn	38.3	39.7	39.7	41.2	44.4
Wheat	38.4	38.6	39.0	40.9	42.0
Potato	48.0	74.2	93.8	91.3	73.0
Sweet Potato	38.9	44.9	51.2	49.0	49.0
Rice Flour	39.0	39.0	45.0	43.0	41.0
Sago	40.0	41.0	41.0	41.0	41.0
Tapioca	41.0	51.0	53.0	50.0	49.0

Figures 8 - 14 inclusive show this data plotted as viscosity against temperature. Corn starch, Figure 8, shows a gradually increasing viscosity, indicating that the higher temperatures are necessary to gelatinize this type of starch. There is a decided change in the slope of the curve from two hundred degrees F. to a boil. It would thus seem very important to give corn starch a vigorous boil for at least an hour, in order to render it suitable for sizing purposes. Wheat starch, Figure 9, has a similar curve, but starts gelatinizing at a lower temperature. White potato starch shows two minimum and one maximum, the maximum being around one hundred ninety degrees F. Sweet potato starch, Figure 11, shows a maximum at one hundred eighty degrees F., while tapioca starch, Figure 12, shows a maximum slightly under this. Sago, Figure 14, again shows a constancy, acquiring its maximum viscosity at about one hundred fifty degrees F., and holding it up to a boil.

Figure 15 shows the change in viscosity of corn starch

when it is treated in a solution containing fifteen hundredths per cent sodium hydroxide. It may be seen that a maximum is reached at one hundred sixty degrees, and that the viscosity falls with the rise in temperature.

Figures 16 and 17 show the drop in viscosity with increasing additions of acetic acid to the starch solution.

Some investigators use the "Flow Test" in determining the viscosities of the different starches, and the following data show the relative viscosities of several of the starches. This test was made by making two per cent solutions with the addition of six tenths per cent sodium hydroxide, and allowing them to stand thirty minutes. The viscosities were taken at room temperature. They were then brought to a boil for thirty minutes, and the viscosities again determined.

Table #4.

Solution	Room Temperature 30"	Boil 30"
Corn	49.2	41.6
Wheat	73.2	40.4
Potato	270.0	42.4
Sweet Potato	235.2	43.4
Sago	41.0	40.4
Tapioca	220.0	47.0
Rice	44.4	44.0
Modified Corn	46.0	40.6

It is seen that there is a great loss in viscosity when the solutions are boiled.

In the last test, solutions of the various starches were made up containing fifteen grams of starch to three hun-

dred cc. of solution, boiled one hour and two ply forties yarn washed in each for ten minutes. The yarn was then passed through the squeeze rolls and dried under tension. The relative stiffening properties of the various starches were then determined by measuring the length of the yarn that would stand alone when placed in a clamping device. The percentage of size taken up from the various baths by the yarn was then determined in the regular manner, and single strand breaking tests were made on the remainder of the yarn. Figure 18 shows the percentage of size taken up from the various baths.

Table #5.

Solution	Length of Yarn Standing Alone	Per Cent Size Taken Up	Tensile Strength
Corn	4 1/16"	3.32	279.9
Wheat	4¼"	3.86	280.8
White Potato	3¾"	4.92	280.5
Sweet Potato	4⅛"	4.68	292.5
Modified Corn	5"	7.74	283.5
Dextrin	2 5/8"	4.88	251.5
Plain Yarn	2"	----	249.0

The relative stiffening values of the various starches are shown in graph form in Figure 19. These values were calculated relative to the stiffening properties of corn starch, the weight of starch taken up being included in the calculation.

By the formula $a : b = \frac{l\, w_1}{l_1 w}$

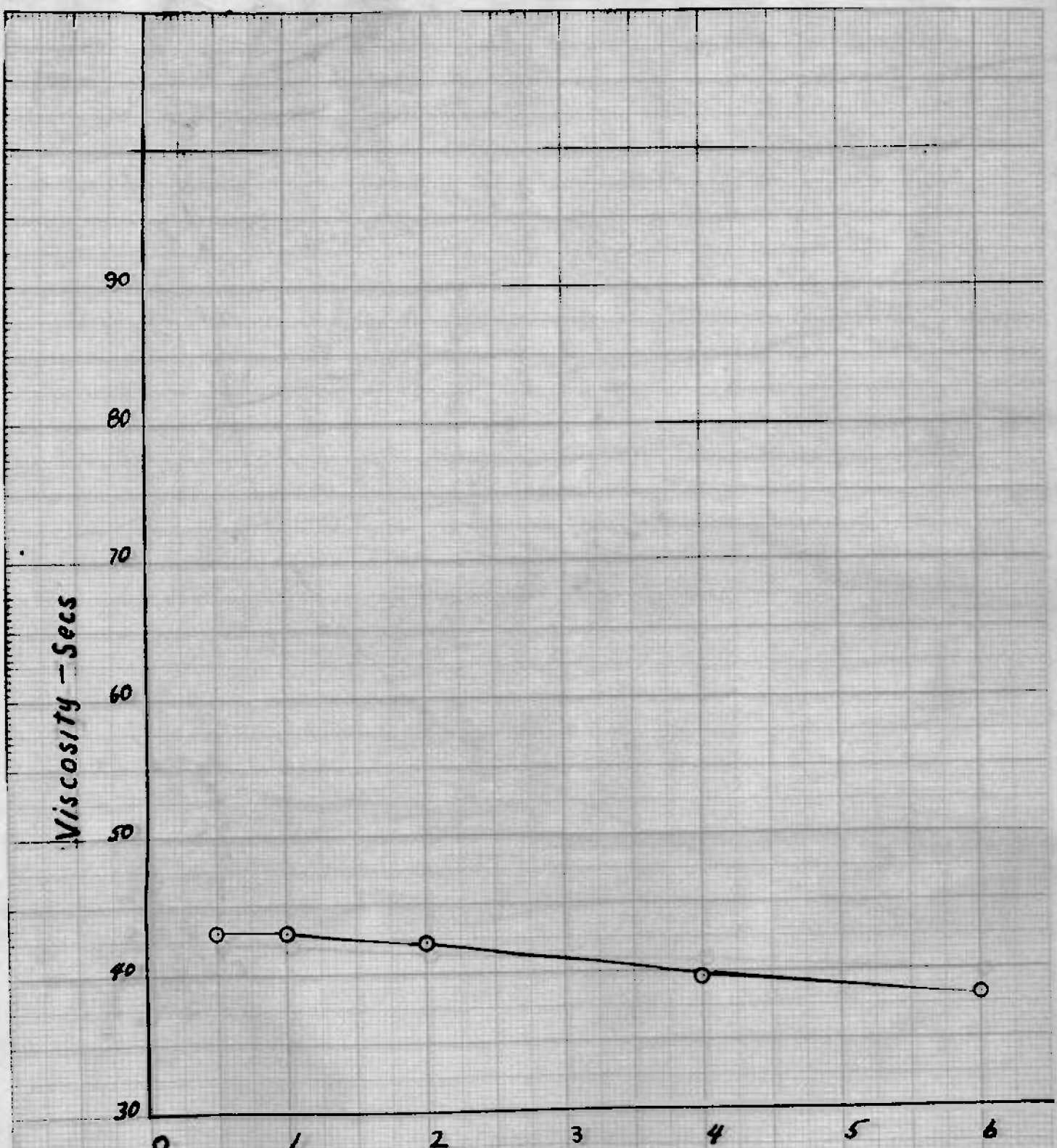
where w equals the weight of corn starch on the yarn,

w_1 " " " " wheat " " " ",

l equals the length of the protruding yarn sized with corn starch,

l_1 equals the length of the protruding yarn sized with potato starch,

when the values for l, l_1, w and w_1 are known, the ratio of the stiffening properties of corn to wheat, $\frac{a}{b}$, may be calculated. The reciprocals of these values were plotted on the graph.



Corn Starch

Fig 1

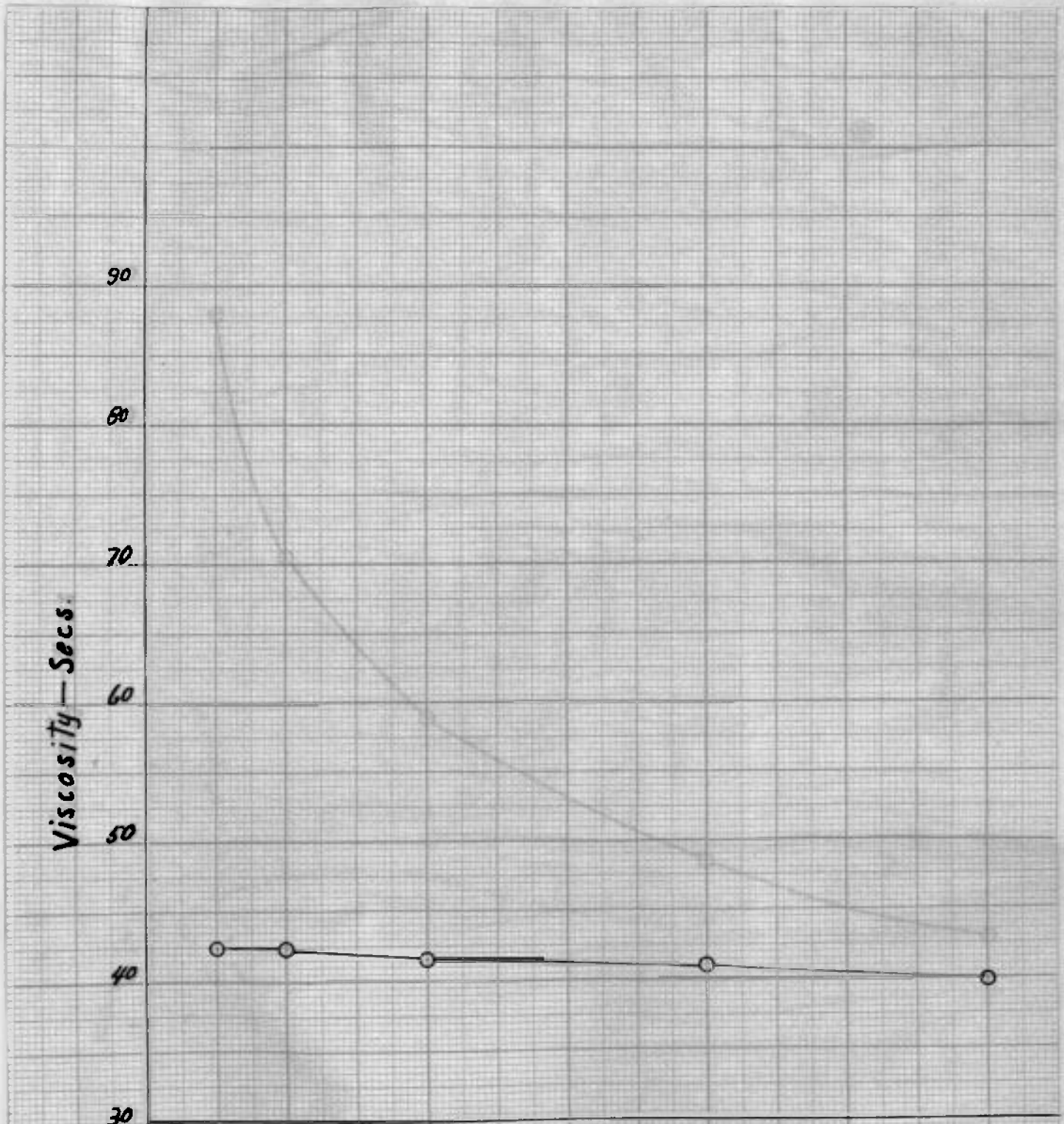
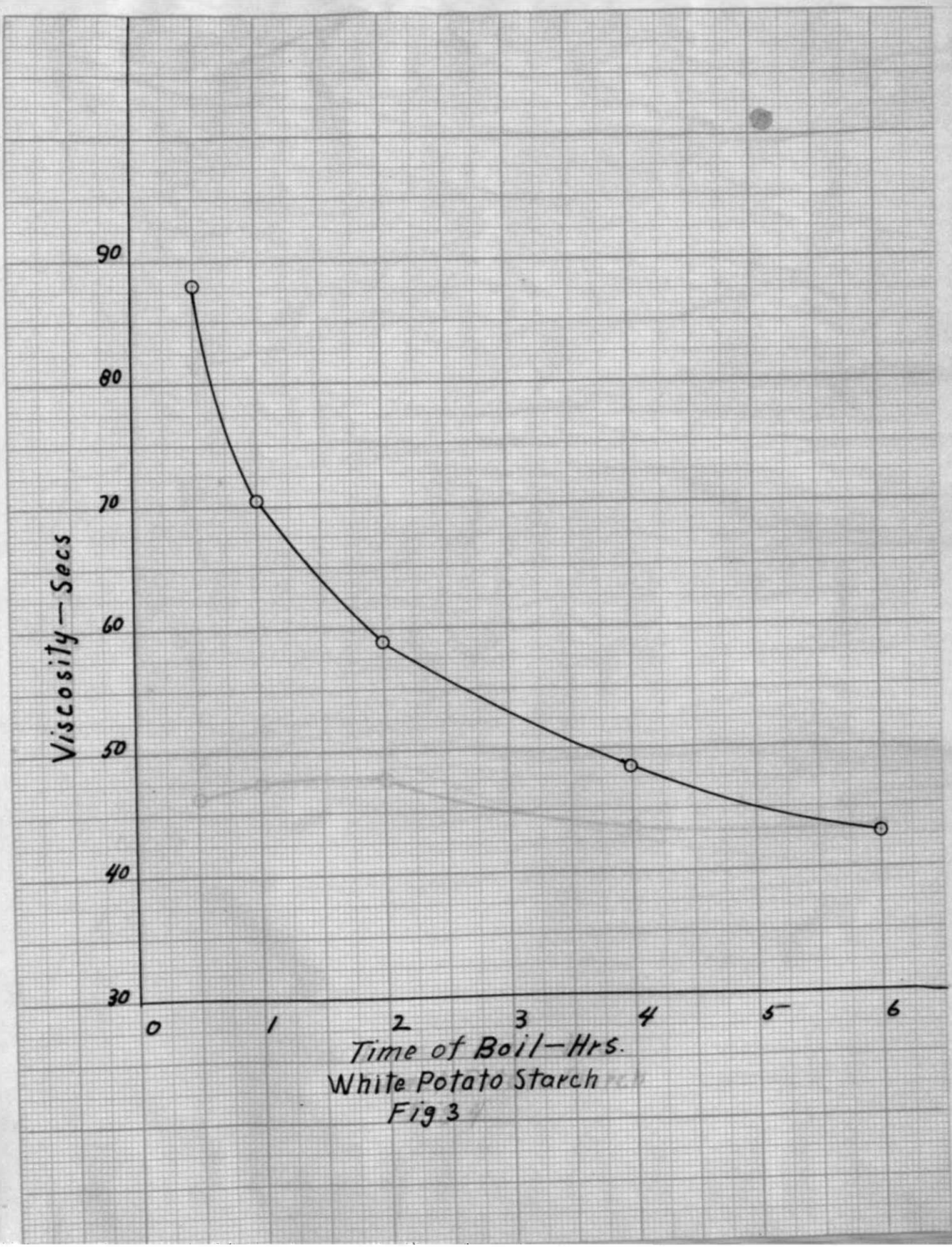
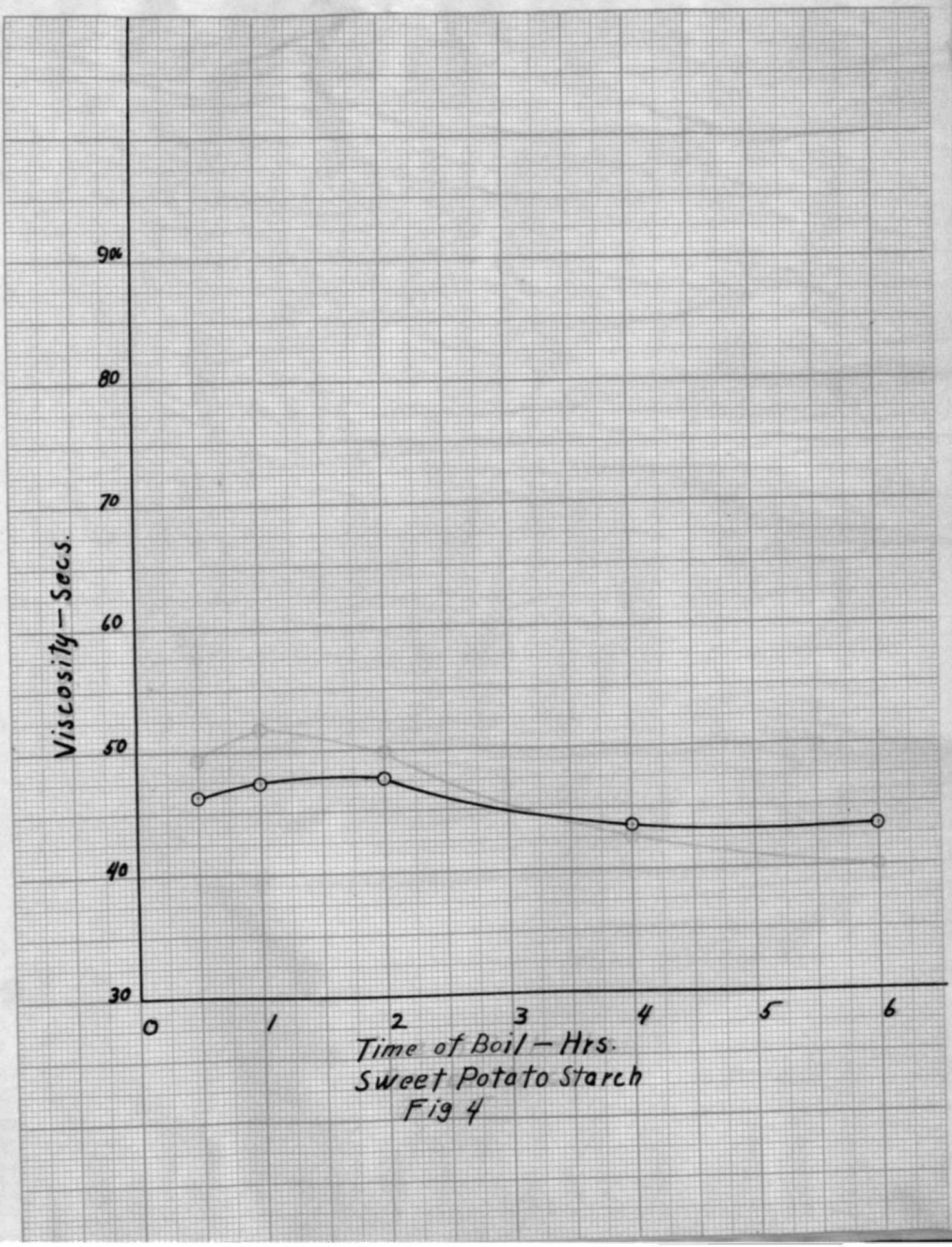


Fig 2



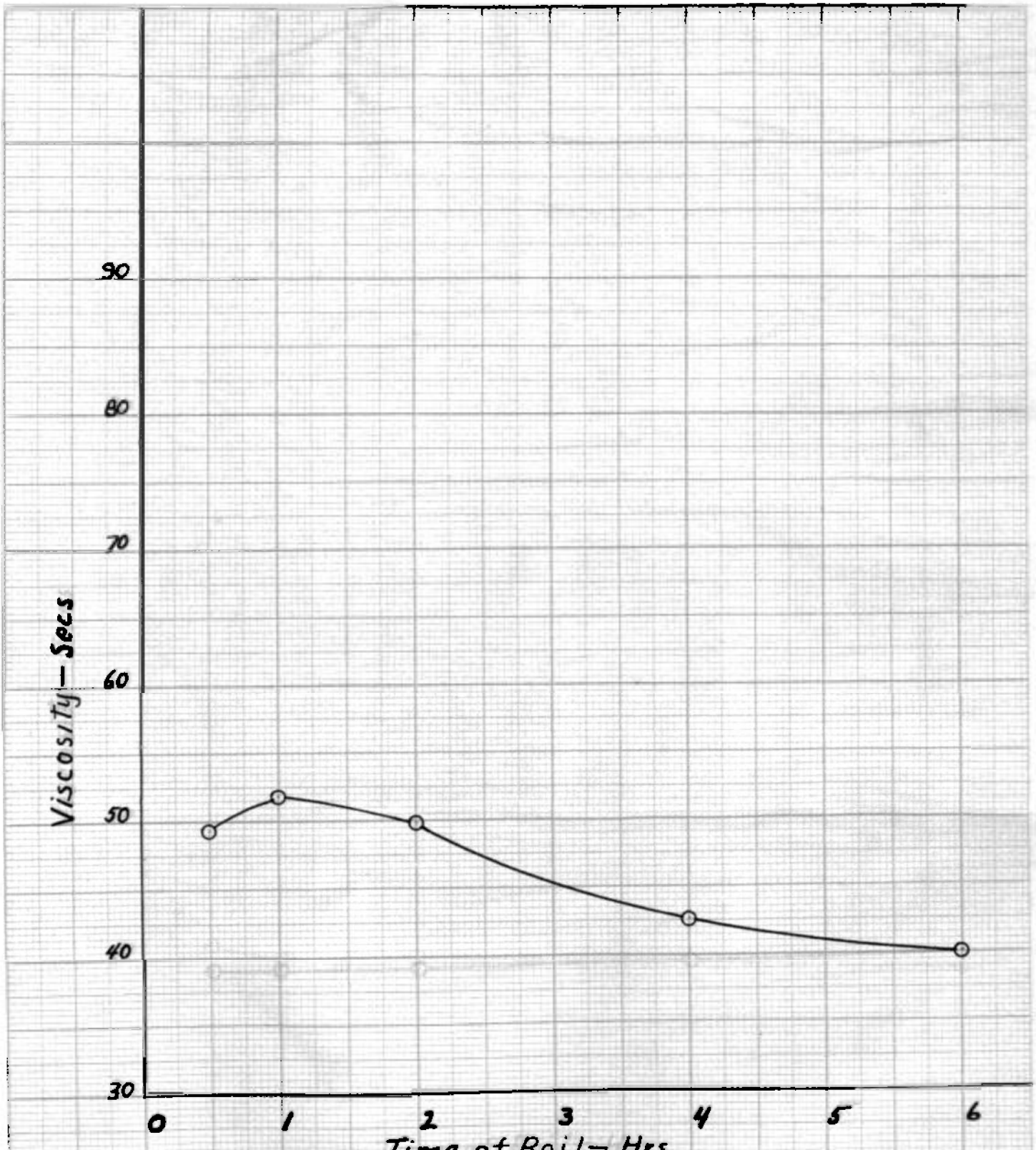
White Potato Starch

Fig 3



Sweet Potato Starch

Fig 4



Tapioca Starch

Fig 6

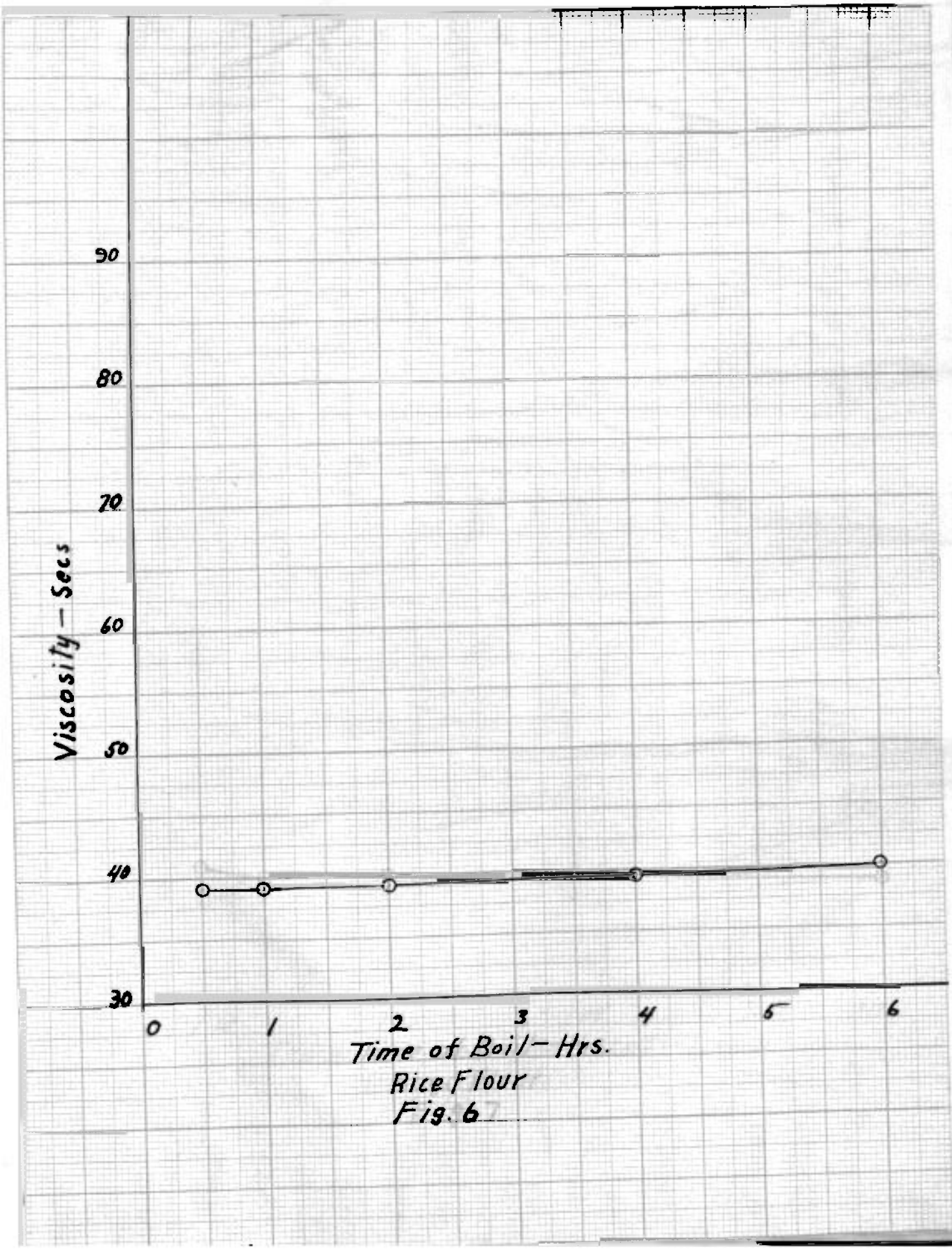
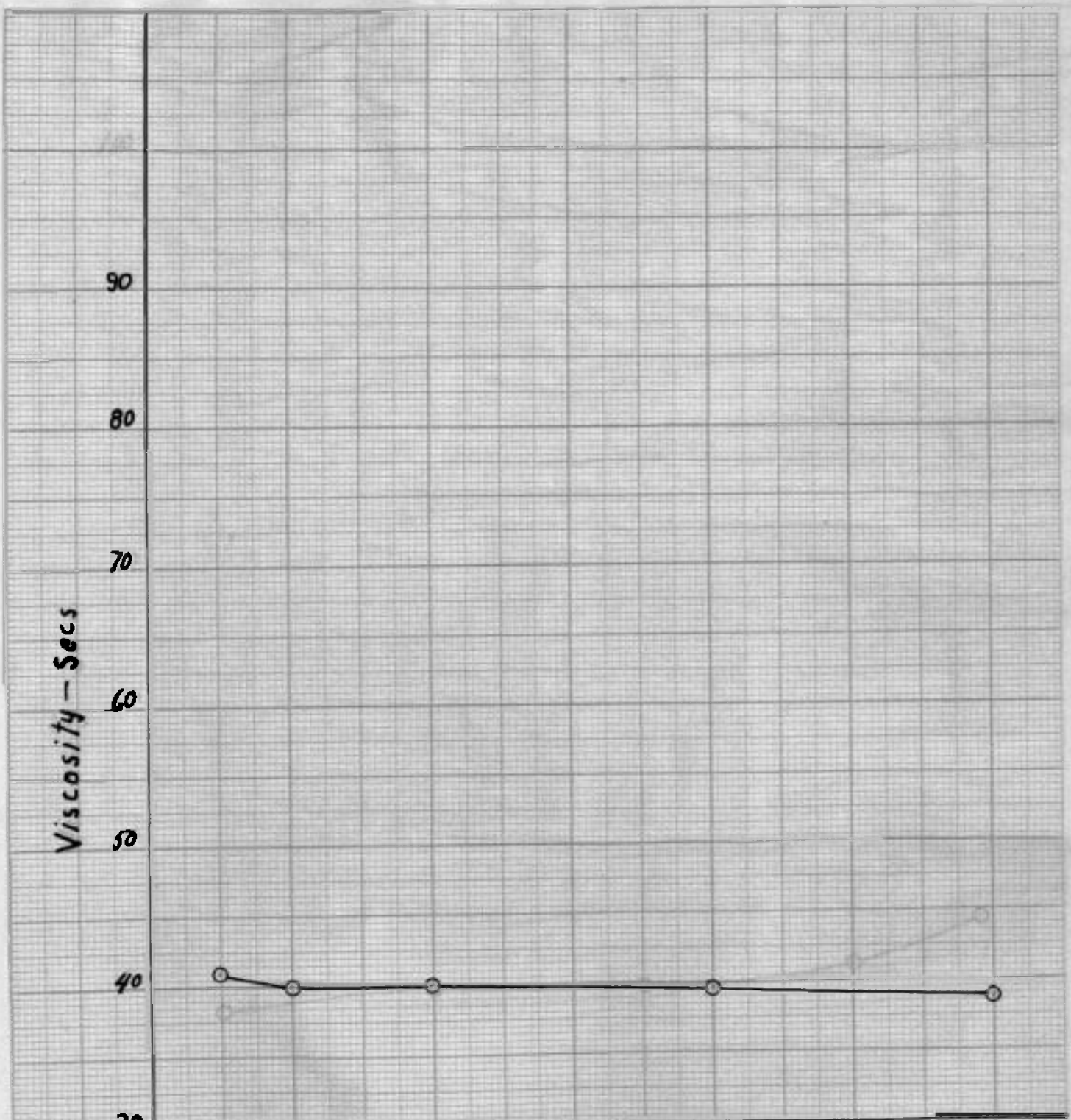
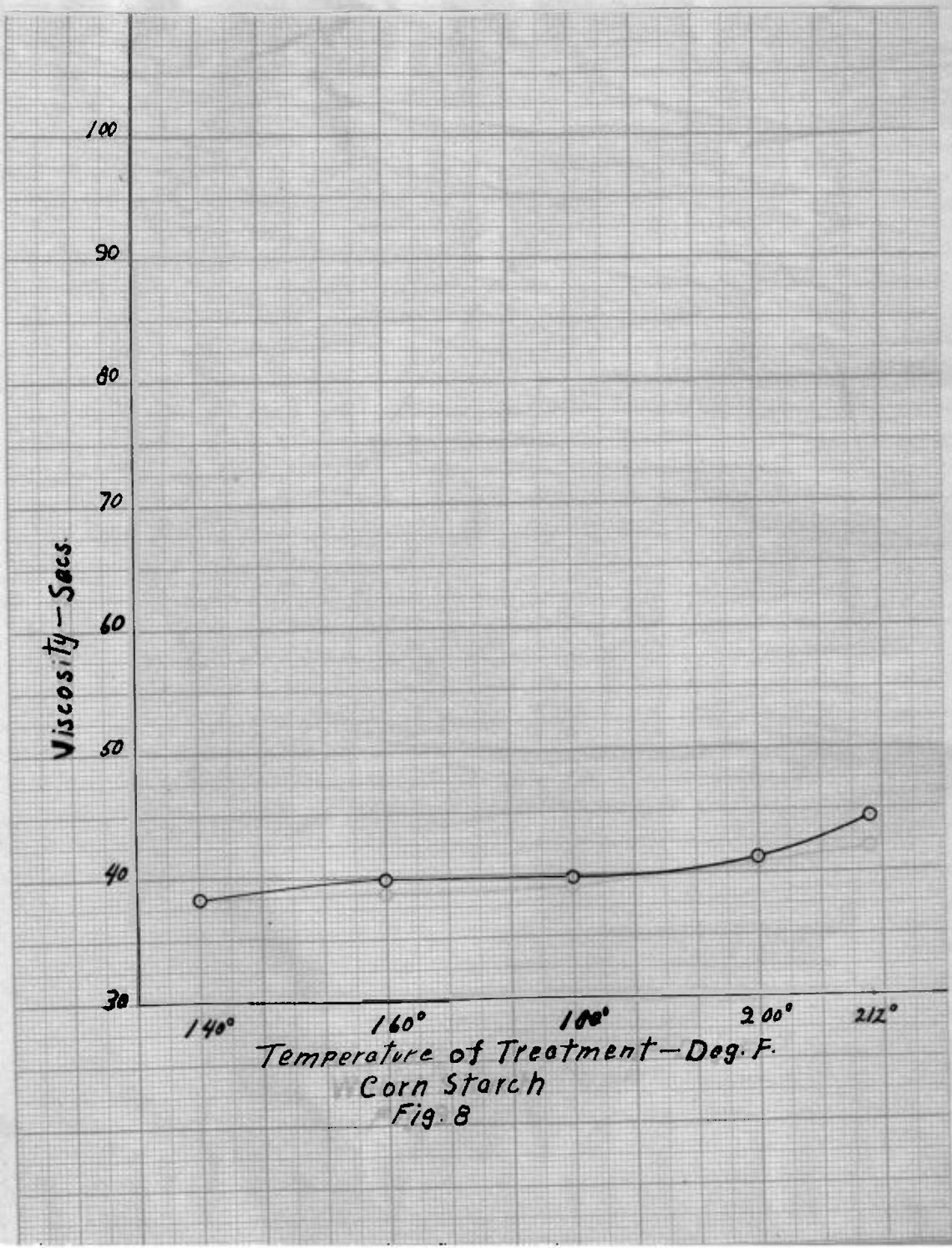

90
80
70
60
50
40
30
Viscosity — Secs
0
1
2
3
4
5
6
Time of Boil — Hrs.
Rice Flour

Fig. 6



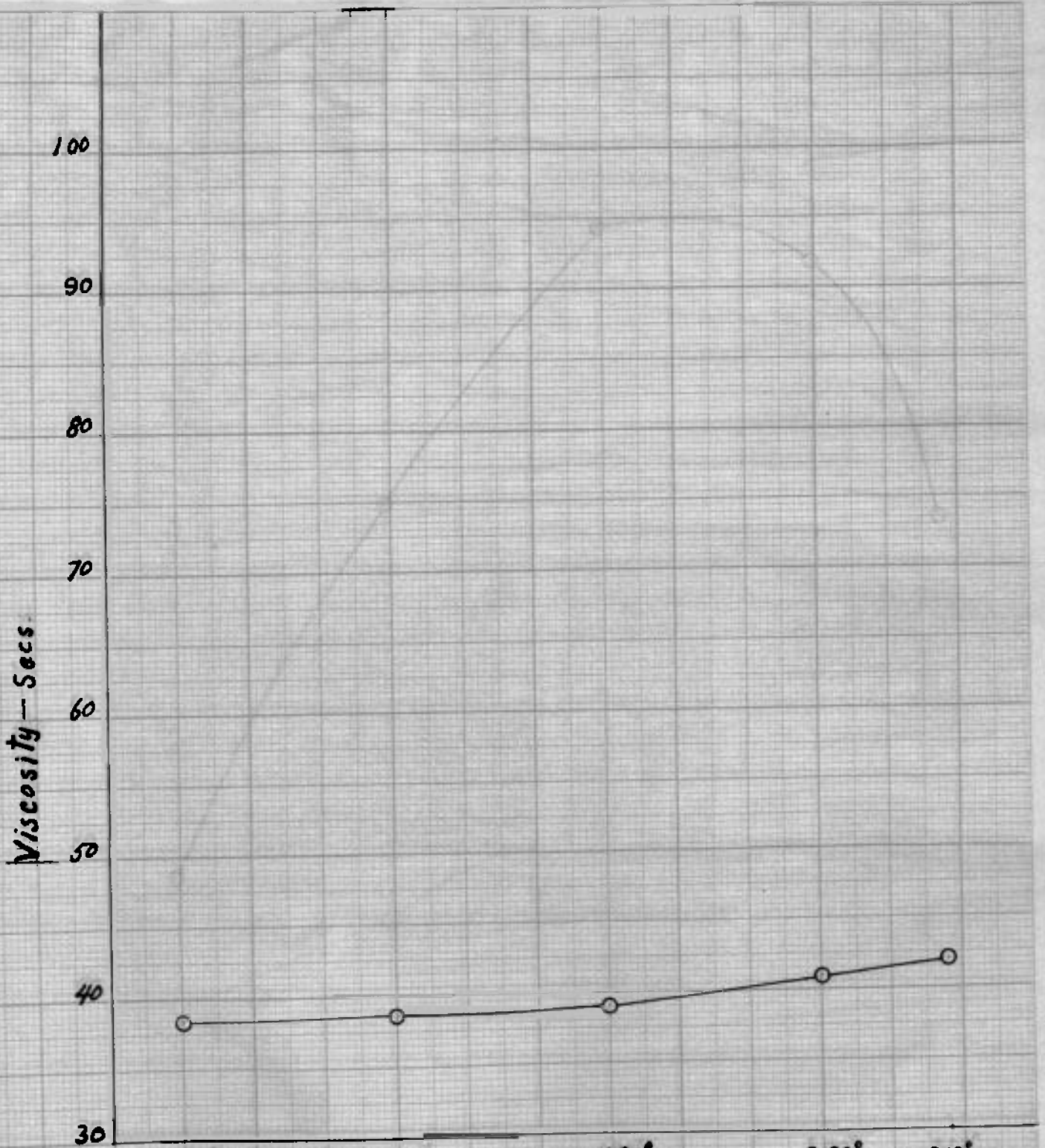
Sago Flour

Fig. 7



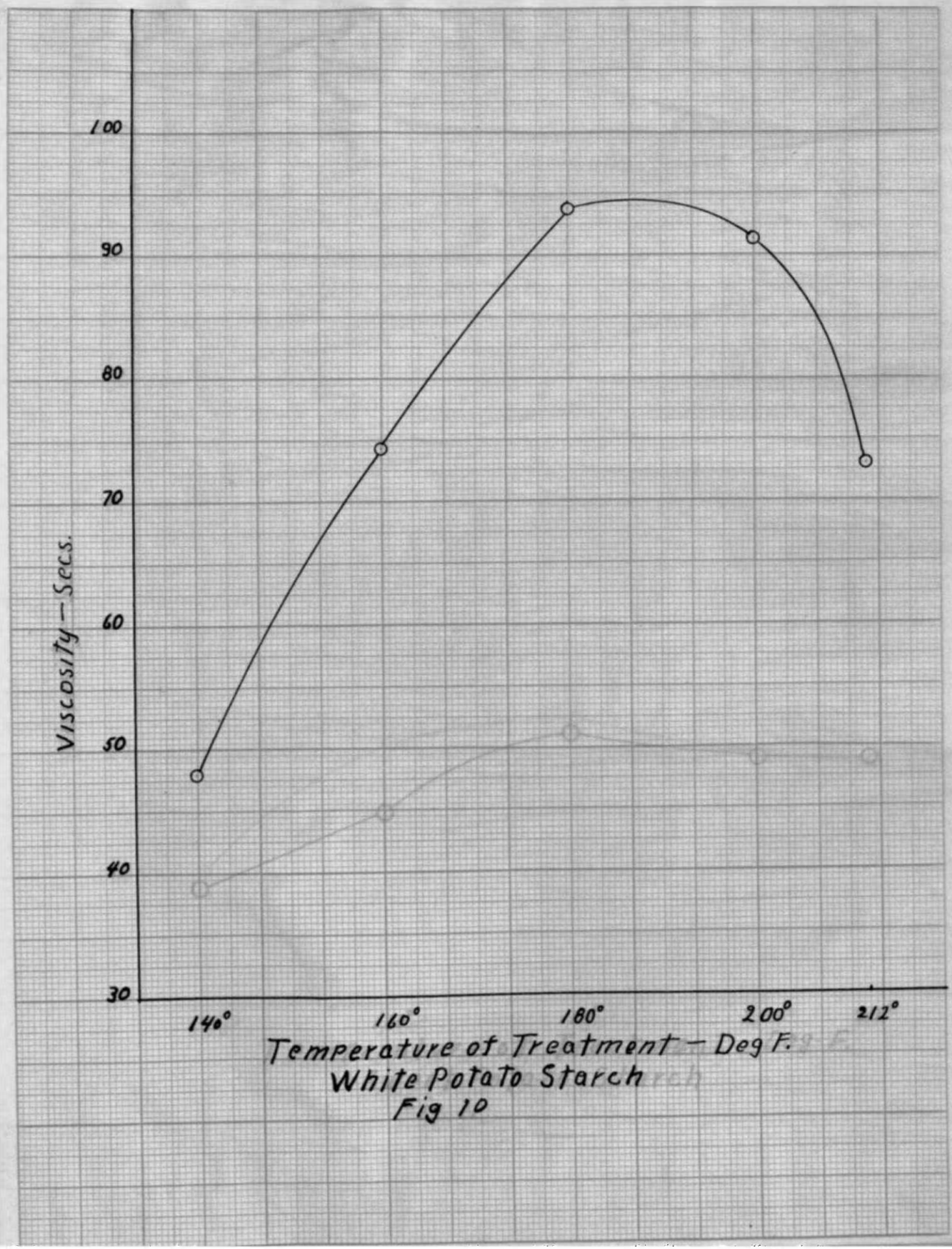
Corn Starch

Fig. 8



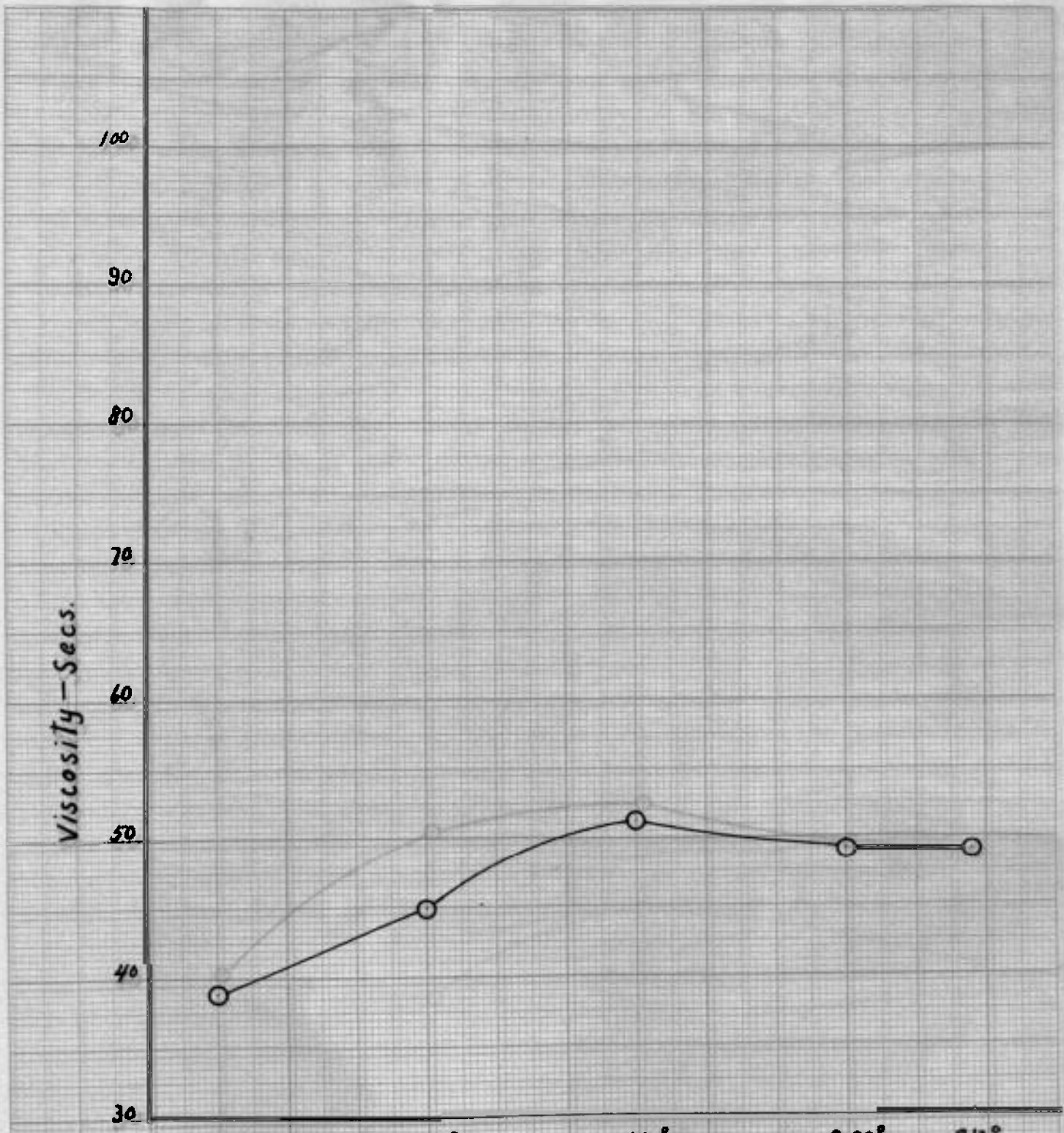
Wheat Starch

Fig 9



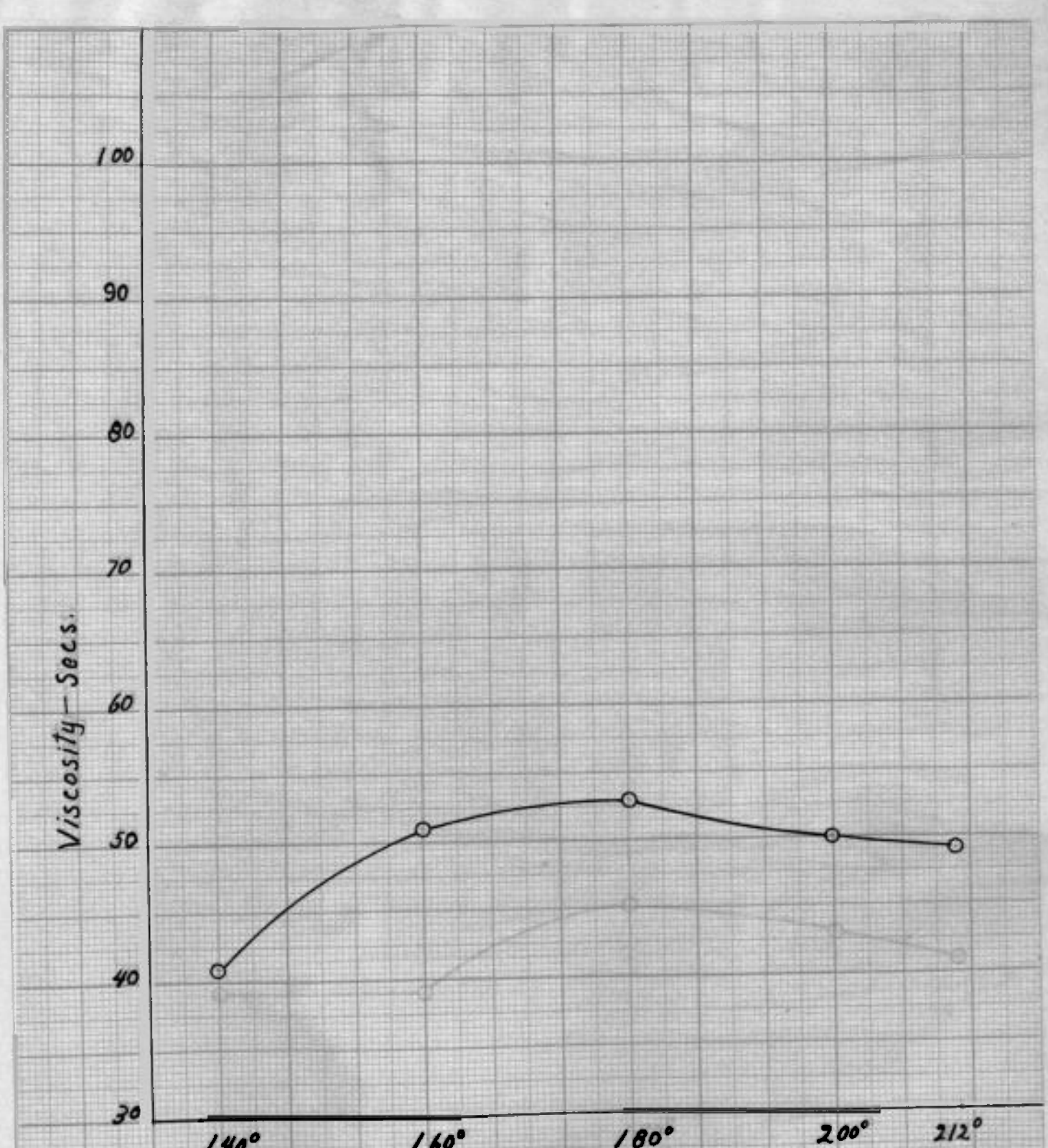
White Potato Starch

Fig 10



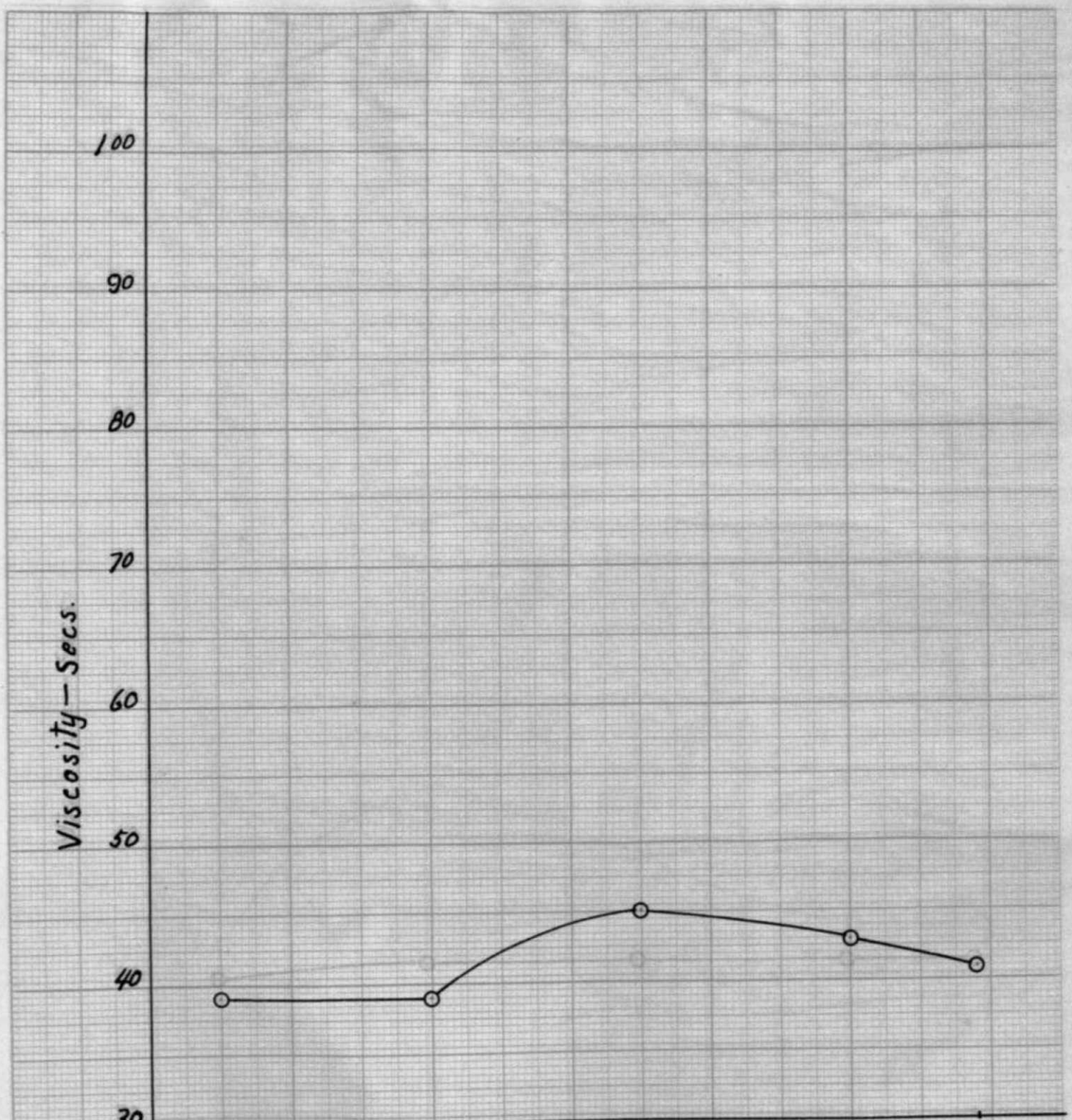
Sweet Potato Starch

Fig 11



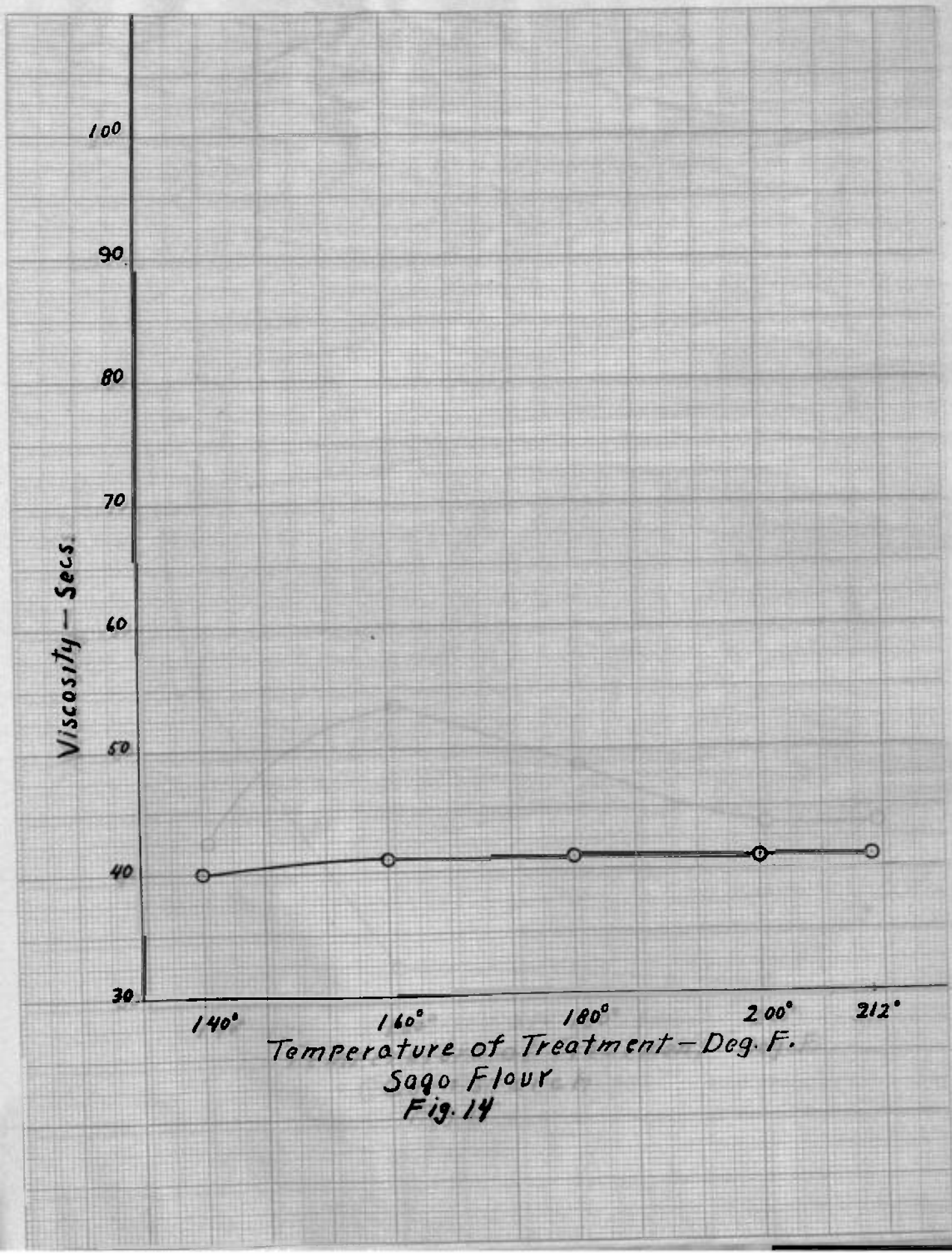
Tapioca Starch

Fig 12



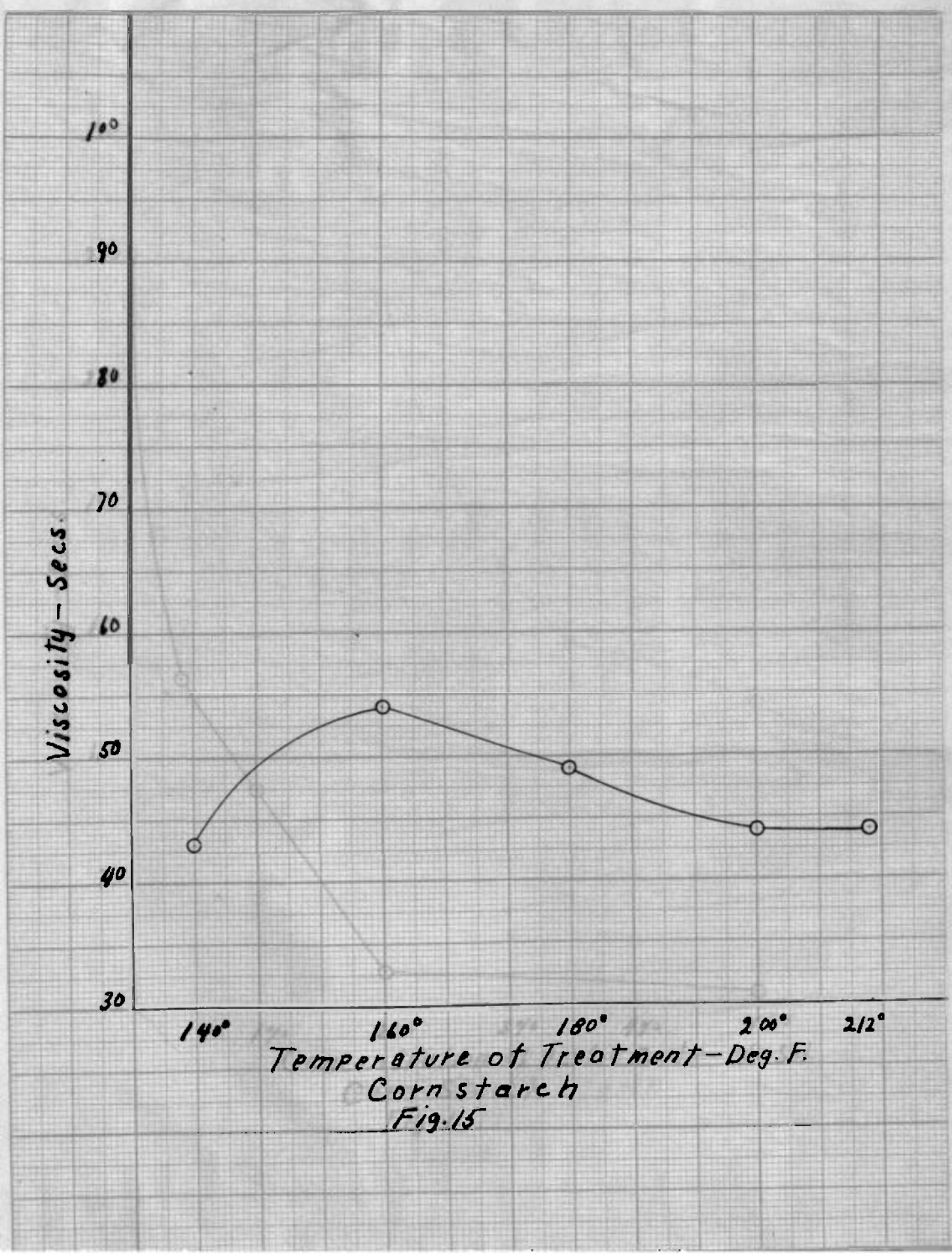
Rice Flour

Fig. 13



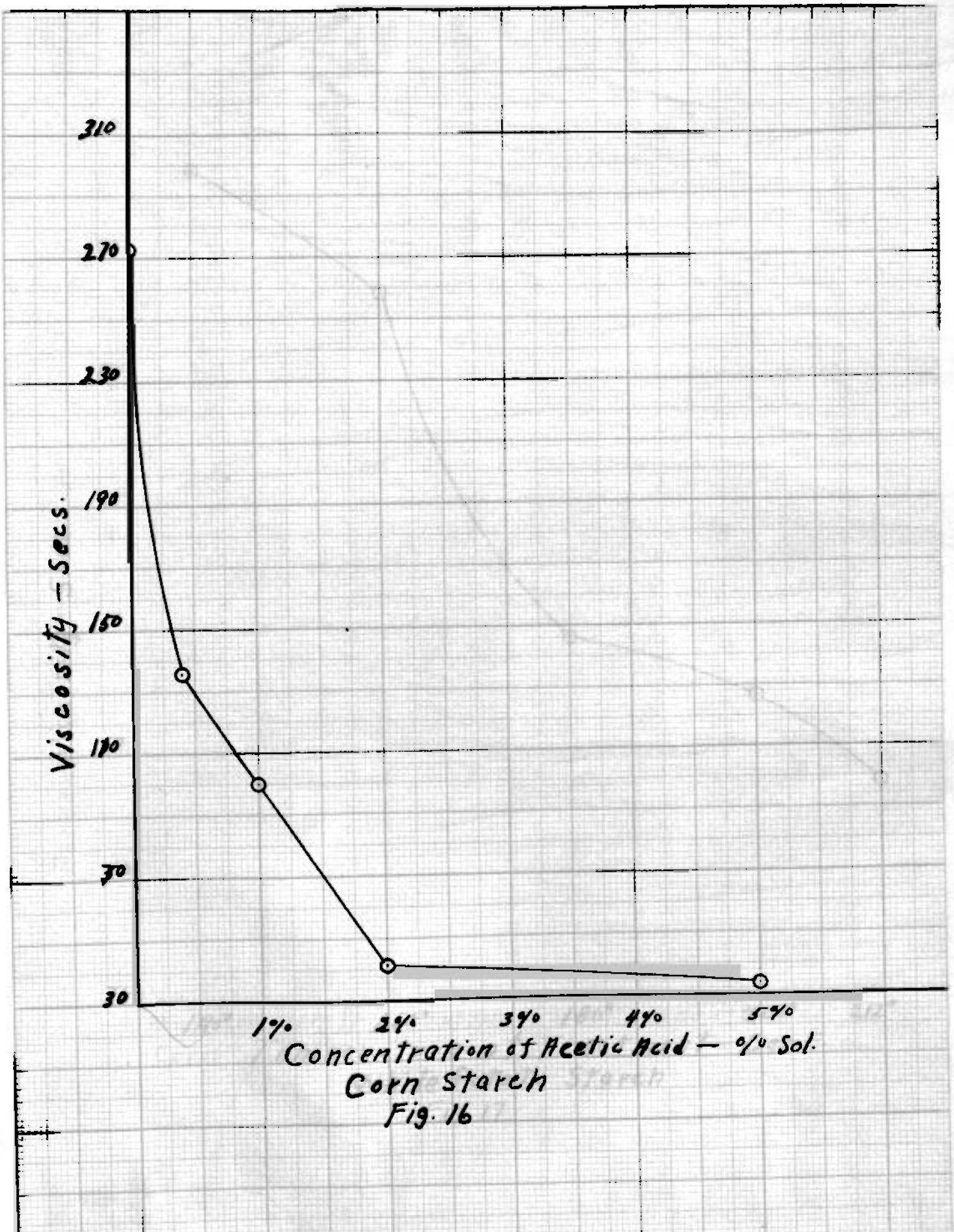
Sago Flour

Fig. 14



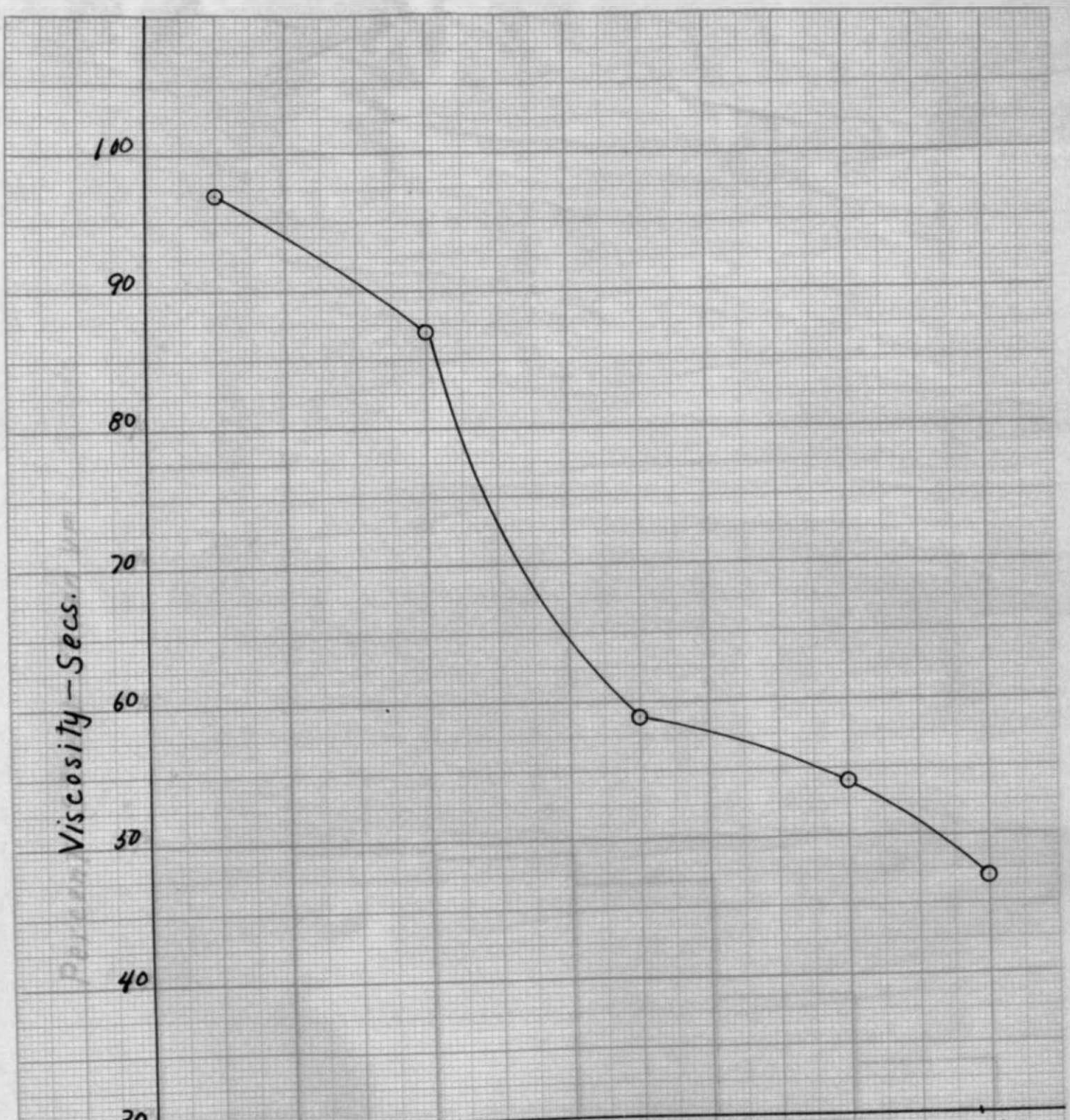
Corn starch

Fig. 15



Corn Starch

Fig. 16



White Potato Starch

Fig. 17

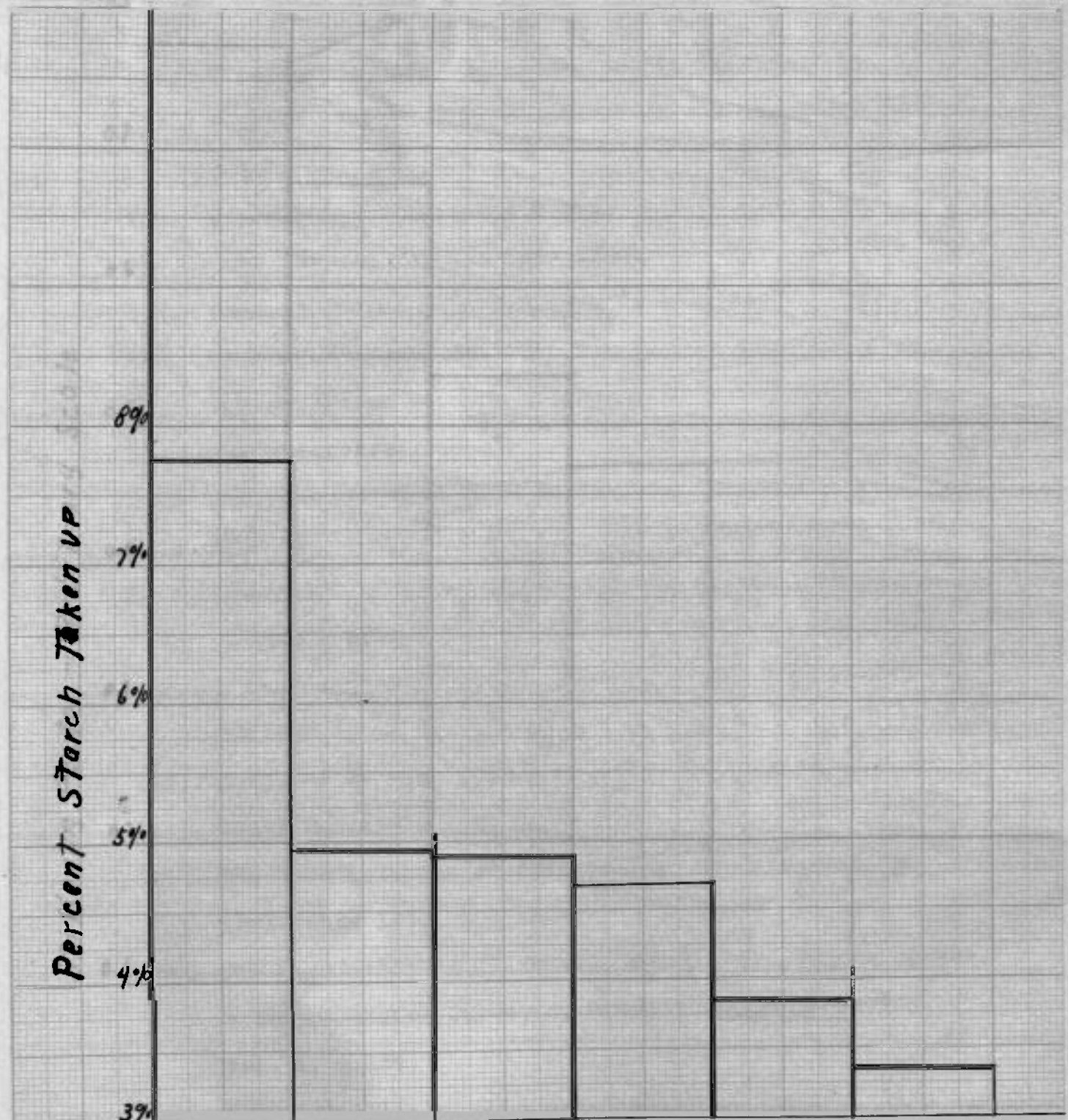

Percent Starch Taken up
8%
7%
6%
5%
4%
3%
Modified Corn
White Potato
Dextrin
Sweet Potato
Wheat
Corn

Fig. 18

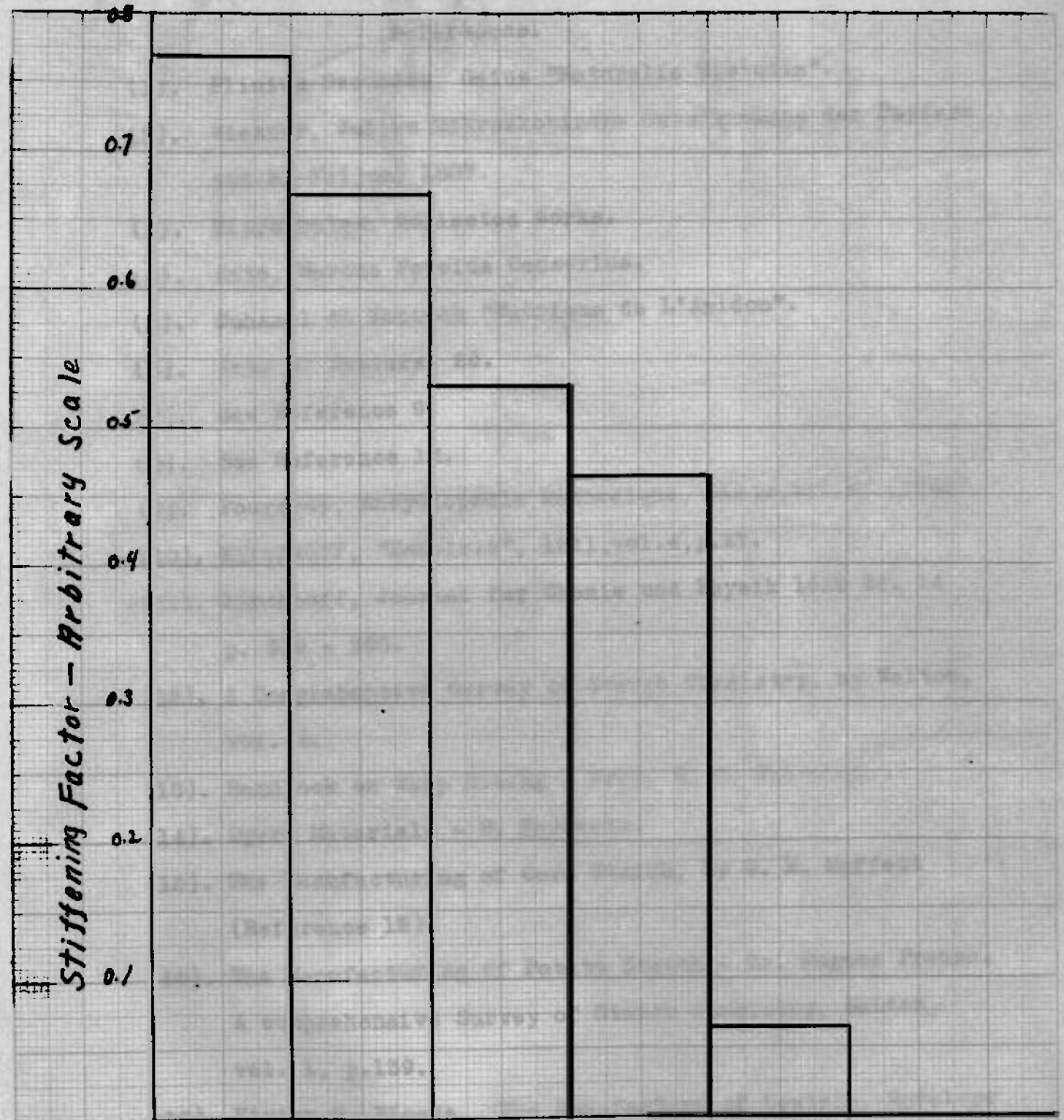

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Stiffening Factor – Arbitrary Scale
Wheat
Sweet Potato
White Potato
Modified Corn
Untreated

Fig. 19

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